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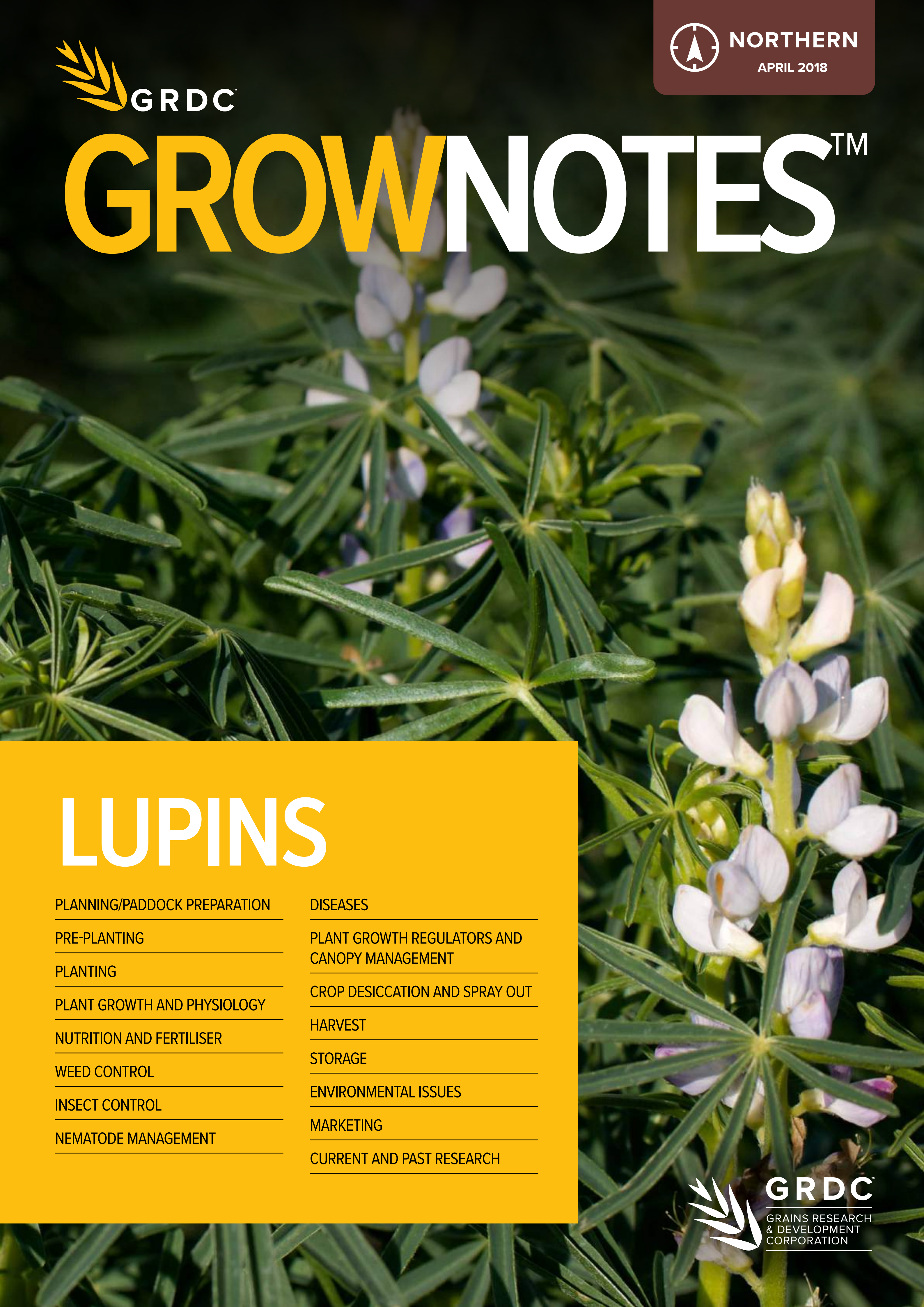

LUPINS

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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Introduction

Key messages

- Lupin is one of the highest produced pulse crop in Australia.
- There are two types of lupin grown in Australia; Albus lupin and the narrow-leaf albus lupin.
- The crop is grown mostly to produce stock feed, but there is a small, but growing market for lupin grain for human consumption.
- Lupin can be utilised as a profitable break crop in cereal cropping sequences; fixing nitrogen, breaking disease cycles and managing weed numbers.

A.1 Crop overview

There are more than 200 species of *Lupinus* across the world. Most of the economically important species come from the Mediterranean region and have large seeds. Lupins belong to a diverse genus of the legume family that is characterised by long flowering spikes with a range of different colours. Lupins are members of the legume family (subfamily Papilioniodeae) containing both herbaceous annual and shrubby perennial types with attractive tall flowers.

Lupin is the largest pulse crop grown in Australia, having a strong domestic as well as export market. There are two types of lupin grown in Australia – narrow-leaf lupin and albus lupin – which have different growth requirements, markets and end-uses. The main type grown in Australia is the narrow-leaf lupin (*Lupinus angustifolius*, Photo 1) the vast majority of which is grown in Western Australia. A smaller area of albus lupin (*L. albus*), is grown in all three Australian grain growing regions.

Photo 1: *Lupin crop near Ardlethan NSW.*

Photo: A Mostead

Choosing the right variety for the right paddock is central to incorporating lupin into a cropping rotation to improve profitability and productivity. [1]

Lupins are the fifth largest winter grain crop in Australia, and Australia grows more than 85% of the world's lupins (Photo 2 Table 1, Figure 1). The biggest export destinations have been the EU, Japan and Korea. Over recent years, national lupin

1 Pulse Australia (2017) Lupin. http://www.pulseaus.com.au/growing-pulses/bmp/lupin

production has averaged 750,000 tonnes per year. Lupins generally compete against soybeans in export markets and are typically valued at 70–75% of the price of soybean meal. Soybean meal prices can be used as a guide to the price of lupin. Lupins have traditionally been exported from Australia as whole grain but are likely to be increasingly sold as the higher protein kernel meal.

Table 1: *Area ('000ha) and production ('000 tonnes) of lupins planted for grain in Australia in 2016. Source Grain Yearbook 2016.*

NSW		Vic		WA		SA		Australia total	
Area	Production	Area	Production	Area	Production	Area	Production	Area	Production
51	66	33	60	361	805	70	100	515	1031

Photo 2: *Lupins being packaged for export.*

Photo: Evan Collins

Lupins are suited to acid and sandy soils and play an important role in breaking cereal disease cycles and adding fixed nitrogen to cropping systems.

Lupins have a unique combination of high protein, high fibre, low oil and virtually no starch. [2]

Lupin has three main uses:

1. in livestock feeding rations in extensive and intensive production systems
2. in human consumption
3. in crop rotations for its ability to add nitrogen and increase the availability of phosphorus in soils. [3]

A.1.1 Albus

The albus or white lupin (*Lupinus albus*) accounts for 20% of the area sown to lupin in Australia, with New South Wales (NSW) being one of the biggest producers. Albus lupins produce larger beans and have broader leaves than the narrow-leaf lupin, and is more commonly grown for human consumption. Albus lupin has a higher protein content (around 46%) than narrow-leafed lupin (around 41%). Albus lupin produces a flat, squarish seed that is larger than the seed of the narrow-leafed lupin (Figure 3).

2 S Watt (2016) Ground Cover Issue 122: AGT Brings lupins into its fold. GRDC. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-122-May-Jun-2016/AGT-brings-lupins-into-its-fold

3 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 3: *Albus lupin in flower. Note the broader leaves than the narrow-leaf lupin.*

Source: Natural medicine

Albus lupin makes up around 50% of the NSW lupin crop, making NSW the largest producer (Figure 1). N.B. The discovery of anthracnose in NSW albus lupins crops has seen the area sown to albus in NSW has declined rapidly. Exclusion zones are now in place. For more information, contact NSW DPI.

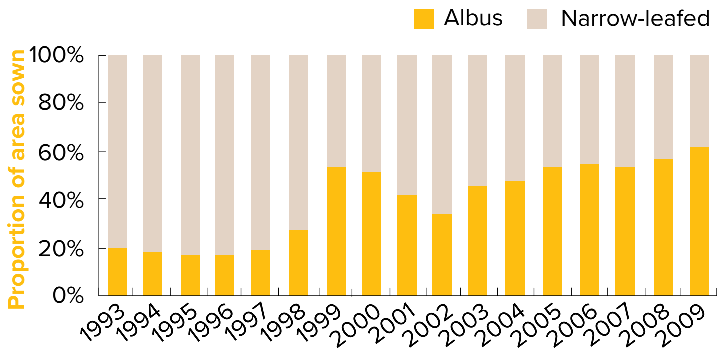


Figure 1: *Proportions of narrow-leafed and albus lupin production in NSW.*

Source: NSW DPI

Albus lupin prefers more fertile, heavier textured and less acidic soils than narrow-leafed lupin. It can achieve higher yields but is more sensitive to frost and waterlogging than narrow-leafed lupin. Albus lupin has a similar growth habit to narrow-leafed lupin, but with a thicker stem, broader leaflets and larger flowers. [4]

A.1.2 Narrow-leaf lupin

Narrow-leafed lupin *(Lupinus angustifolius*) accounts for 80% of the total area sown to lupin in Australia. The seed has a protein content of around 35% and is used mainly as stockfeed. Narrow-leafed lupin seed is round and speckled, and slightly smaller than the seed of field pea or soybean (Photo 4). Narrow-leafed lupin is well suited to light, sandy, acidic soils. It will grow on red clay loams but prefers deep, coarse-textured, free-draining, sandy soils. It grows best in the higher rainfall areas of the central and southern NSW wheat belt. [5]

4 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

5 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 4: *Narrow-leaf lupin beans (top) and in flower (bottom).*

Source: DAFWA

A.1.3 Animal consumption

The vast majority of global lupin production is used by stockfeed manufacturers for animal feed (Photo 5). Lupins are mostly utilised by stockfeed manufacturers in compound feed rations. Ruminants are the biggest users followed by pigs and poultry. There is increasing utilisation in aquaculture and for human food where they are valued for both their nutritional and functional properties.

Photo 5: *Lupin meal consisting of lupin hulls and particles of lupin kernels. The product is used to feed ruminants, monogastrics and increasingly in aquaculture.*

Source: Coorow Seeds

The nutritional value of the different lupin species varies which has implications for end-use. All species are largely free of anti-nutritional factors.

In the first instance lupins are valued in comparison to other protein commodities. However, protein is not the sole price determinant as lupin also provides a significant energy contribution to a stockfeed ration. Premiums for this energy value are particularly the case where lupins are used in ruminant feed. [6]

For more information on selecting lupin for feed grain, see Section 2: Pre-planting – Lupin for feed grain.

A.1.4 Human consumption

Less than 4% of global production is currently consumed as human food. Food Standards Australia approved lupins for human consumption in the late 1980s, but this end use has been very limited. However, in Europe about 500,000 tonnes of foods containing lupin ingredients are consumed each year, primarily in wheat-based bakery products. Lupin beans can be eaten whole or ground into flour to form the base of a number of food products (Photo 6).

6 Lupins.org (2016) Feed and Food. GIWA. http://www.lupins.org/feed/

Photo 6: *A loaf of bread made with lupin flour, sitting on a bed of Australian sweet lupins.*

Source: DAFWA.

Health benefits

A study at the University of Western Australia (UWA), found that using flour containing 40% lupin beans helps with cholesterol and insulin concentrations and blood pressure. These health benefits are linked to the lupin's nutrient structure, which is high in fibre and protein and low in fat and starch. The beans can also be easily ground into flour ready for use in food preparation. This is why there is growing interest among health professionals in lupins. The lupin bean contains about 40% protein and 30% dietary fibre with negligible carbohydrate. Lupin-kernel flour has a unique macronutrient composition that can be used to increase fibre and protein content while simultaneously reducing carbohydrates. [7]

Research has also shown that consuming foods enriched with Australian sweet lupin can provide a feeling of 'fullness' and result in people eating less and consuming fewer kilojoules. Other possible health benefits of eating lupins include a more balanced blood glucose level, a lowering of cholesterol and improved bowel health. [8]

A.2 Growing region

In Australia, most lupin production occurs in the winter/spring rain-fed parts of south-western Western Australia followed by South Australia, southern New South Wales and Victoria (Figure 2).

7 M Branagh-McConachy (2014) Ground Cover Issue 108: Dietitians taking lupins to heart. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-108-Jan-Feb-2014/Dietitians-taking-lupins-to-heart

8 I Wilkinson (2017) Western Australian Lupin industry. DAFWA. https://www.agric.wa.gov.au/grains-research-development/western-australian-lupin-industry

Figure 2: *Lupin production regions in Australia.*

Source: NSW DPI

There is a significant proportion of *L. albus* produced in NSW and Vic, while production in WA and SA is dominated by *L. angustifolius*. The main lupin production area in NSW is in the south-east of the State. The NSW DPI Southern Pulse Survey 2015–16 indicated that lupins make up 49% of the southern NSW pulse area. A mix of both narrow-leafed and albus lupin is grown. In the north-west, production is predominantly albus lupin; because of their susceptibility to cucumber mosaic virus, very few narrow-leafed crops are grown. [9]

In October 2016 lupin anthracnose was detected for the first time in commercial crops in the eastern Riverina region of NSW. Natural hosts of lupin anthracnose are not established in NSW and as the infected crops were relatively isolated, successful eradication of the disease was considered possible and an eradication program is now in place.

All lupins crops found to be infected with lupin anthracnose in 2016 have been either destroyed or sold under special conditions to prevent further spread of the disease.

The eradication program also includes the creation of the lupin anthracnose biosecurity zone (LABZ) within which special conditions apply to the growing of ornamental and commercial lupins.

9 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

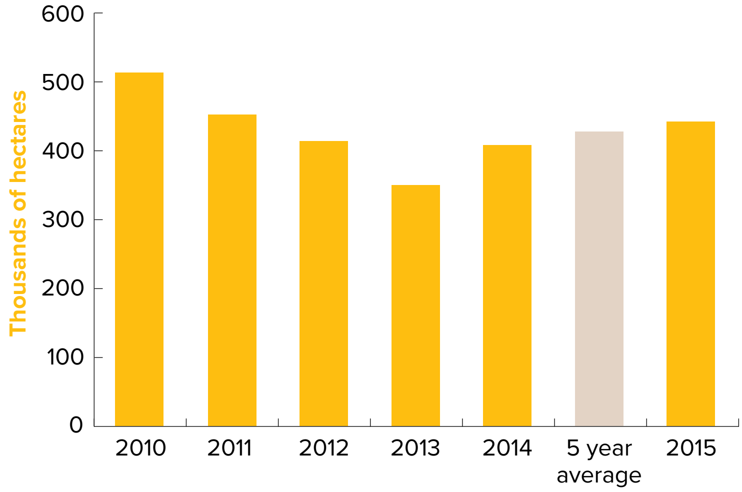


Figure 3: *Area (ha) sown to lupin in New South Wales.*

Source: Pulse Australia

The Northern growing region stretches from southern NSW to northern Queensland. It has relatively high seasonal rainfall and production variability compared with the other two regions. Both summer and winter crops are important for profit. Yield depends, to a significant degree, on conservation of soil moisture from summer-dominant rainfall. The Northern Region has the highest diversity of crop production, including maize, sorghum and tropical pulses as well as wheat, barley, winter-growing pulses and oilseeds

Key characteristics of the Northern growing region include:

- High inherent soil fertility
- Yield depends upon conservation of soil moisture from summer rainfall
- Substantial enterprise size
- Diversity in crop choice, need for new crops e.g. pulses
- Premiumum on high-protein wheats for export and domestic markets
- High-potential yields
- Competition with cotton

Winter crops grown in the Northern region include; wheat, barley, oats, chickpeas, triticale, faba beans, lupins, field peas, canola, millet/panicum, safflower and linseed.

Summer crops grown in the Northern region include; sorghum, sunflowers, maize, mungbeans, soybeans, cotton and peanuts.

A.3 Brief history

Over the last 2000 years, lupins have been grown for both agricultural and aesthetic purposes. The bean has been grown and harvested for human and animal consumption, while the plant has been grown in gardens for its elaborate flowers.

In Australia, lupins were introduced during the mid-19th century to Victoria and South Australia. By the turn of the century, State Departments of Agriculture were promoting their use as a fodder and green manure crop as the knowledge of the usefulness of leguminous crops was discovered. Bacterial cultures were made available to farmers once scientists discovered that successful nodulation under Australian conditions was not generally possible without inoculation.

The production and uses of lupin in Australia has varied over the last few decades (Tables 1, Figure 3 and Table 2).

Table 2: *Supply and disposal (Kt) of Australian lupin crops between 2012 and 2016. Grain Yearbook 2017.*

Lupin	2012	2013	2014	2015	2016
Production	459	626	549	607	1031
Domestic use and stocks	290	310	306	244	436
Exports	416	274	270	220	595

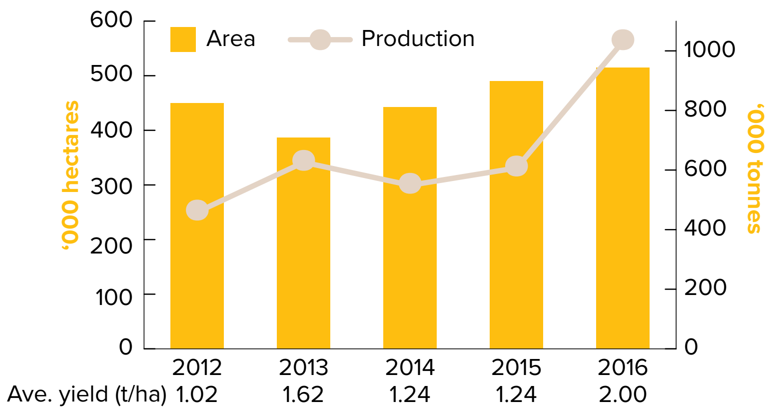


Figure 4: *Australian lupin production.*

Source: Grain Yearbook 2017.

Table 3: *Area ('000s of ha) sown to Lupin in each state over the last two decades.*

	NSW	VIC	WA	SA	National
1992	99	53	823	58	1,032
1993	96	55	929	70	1150
1994	107	64	1152	83	1406
1995	92	51	1100	80	1322
1996	63	43	1097	103	1306
1997	80	41	1207	96	1424
1998	106	42	1180	79	1407
1999	135	35	1104	73	1347
2000	92	34	987	67	1180
2001	106	33	920	80	1139
2002	100	40	795	89	1024
2003	42	30	500	65	638
2004	63	35	677	69	844
2005	26	20	650	57	754
2006	55	30	350	65	500
2007	62	31	300	61	454
2008	55	28	267	70	420
2009	66	26	326	69	486
2010	90	27	391	60	568

	NSW	VIC	WA	SA	National
2011	68	23	334	65	490
2012	58	29	303	61	451
2013	57	28	246	56	387
2014	56	32	289	68	446
2015	62	33	325	68	488

Source: Pulse Australia

MORE INFORMATION

Eastern Australia Lupin breeding

Lupin breeding in Australia – NSW agriculture component

An economic analysis of GRDC investment in nation lupin breeding for southern Australia

A.3.1 Lupin breeding

The Grains and Research Development Corporation (GRDC) and the Department of Agriculture and Fisheries Western Australia (DAFWA) have co-invested in the breeding and commercial release of lupin varieties for the past 20 years. Breeding programs produced a number of varieties suited to eastern Australia and the Northern growing region between 2004 and 2009. Important traits for breeding were yield, disease and pest resistance, and herbicide tolerance. Improvements in these traits were delivered in the new varieties released during the program. Higher yields and disease resistance can translate into higher profits from the lupin crop, in turn increasing the attractiveness of lupins in a cereal rotation.

More recently (2016), Australian Grain Technologies (AGT) added lupins to its grains breeding portfolio. Commercial breeding expertise will accelerate the rate of genetic gain in lupin breeding and provide greater certainty for the future of lupin in Australia. [10]

10 S Watt (2016) Ground Cover Issue 122: AGT Brings lupins into its fold. GRDC. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-122-May-Jun-2016/AGT-brings-lupins-into-its-fold

Planning/Paddock preparation

Key messages

- Lupin provides a disease break for cereal crops, can increase nitrogen in the soil and can help for grass weed control within cropping sequences.
- Generally, lupins prefer slightly acidic or neutral, well drained, friable soils of reasonable depth. Lupin species vary in their sensitivity to soil pH and waterlogging.
- If a paddock has been exposed to lupin disease, particularly Lupin Anthracnose, it is recommended that a four-year break is taken between lupin crops. Test seed and soil for lupin disease.
- Avoid sowing sweet lupin within 2 km of a lupin crop.
- Lupin can be direct drilling into the standing cereal stubble. Lupin stubble can then be grazed shortly after harvest.

1.1 Paddock selection

Select paddocks with:

- Good drainage - AAlbus lupins are very susceptible to root rot;
- Sandy textured soils with pH 4.5 – 7 (Calcium Chloride - $CaCl_2$) or above 5.0 for albus and good depth.
- Avoid paddocks sown to narrow-leaf or albus lupins in the last four years. The fungus that causes brown leaf spot in narrow-leafed lupins causes pleiochaeta root rot in albus lupins. [1]
- Avoid saline soils, those subject to waterlogging, alkaline and shallow duplex soils.
- A relatively low broadleaf weed burden as there are limited broadleaf weed control options.
- Ideally paddocks with good stubble from previous year to reduce brown leaf spot risk.
- Ensure that lupins are not planted in paddocks that may be contaminated with bitter lupin seed. Any crops sown from potentially contaminated seed or lupini bean (a large seeded, bitter albus lupin) must be grown at least 2 km away from other albus crops. 17[2]

Pulses have very specific requirements of soil type, place in rotation and sowing time for them to be successfully grown. It is critical to match pulse crops to soil type in a particular paddock.

The paddock should retain standing cereal stubble and be as far away as possible from stubble of the same pulse (Photo 1). Ideally the pulse crop can be no-tilled into standing cereal stubble to help minimise disease (minimum spore splash and aphid activity).

1 K Smith, D Carpenter (1999) Albus lupins. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/157169/pulse-point-08.pdf

2 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 1: *Lupin sown into standing cereal stubble.*

Source: https://grdc.com.au/research/reports/report?id=531

Broadleaf weed pressure should be low – the weed seed bank should have been reduced in previous crops.

Harmful herbicide residues should not be present e.g. sulfonylurea herbicides such as chlorsulfuron from the previous cereal crop, particularly on alkaline soils.

The soil should be free of a significant hard pan – cause of induced waterlogging problems and disease e.g. phytophthora root rot in lupins.

Do not sow a pulse on pulse crop even after a drought. Use yield mapping, observation and soil testing to identify paddock variability and problem areas. [3]

Lupin varieties vary in their ability to grow under different rainfall patterns (Table 1).

Table 1: *Most adapted narrow-leafed lupin varieties for each rainfall zone.*

Rainfall zone (average annual rainfall)		
Low	Medium	High
<375 mm	375–500 mm	>500 mm
Mandelup(D)	Mandelup(D)	Jenabillup(D)
Jenabillup(D)	Jenabillup(D)	PBA Gunyidi(D)
PBA Gunyidi(D)	PBA Gunyidi(D)	PBA Barlock(D)
PBA Jurien(D)	PBA Jurien(D)	PBA Jurien(D)

Source: SARDI

1.1.1 Soil

Lupin is a profitable pulse crop well suited to lighter soil types in central and southern NSW. [4] Lupins have specific requirements for soil pH, drainage, sodicity and exchangeable aluminium as shown in Tables 2 and 3. Narrow-leafed lupins have sparse, deep root systems that are not suited to fine textured or shallow soils.

3 C Mullen (2004) The right pulse in the right paddock at the right time. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/151112/the-right-pulse-in-the-right-paddock-at-the-right-time.pdf

4 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

Table 2: *Guidelines for Pulse Crop Soil Requirements on central NSW soils.*

Crop	Soil Type	Soil pH ($CaCl_2$)	Exchangeable Al% range	Drainage Tolerance (1–5)**	Sodicity in Root Zone. (90 cm) (ESP) +
Lupin – narrow-leaf	Sandy – loams	4.2 – 6.0	20% tolerant	Sensitive (2)	< 1 surface < 3 subsoil
Lupin – Albus	Sandy – loams – clay loams	4.6 – 7.0	Up to 8%	Very sensitive (1)	< 1 surface < 3 subsoil

**No hard pans and good drainage (no puddles after 24 hours from a 50 mm rain event). Hardpans – can aggravate waterlogging and cause artificial waterlogging.
+ Exchangeable Sodium %

Source: NSW DPI

L. angustifolius grows best on deep yellow loamy sands and friable sandy loams. Unsuitable soils include deep white or grey sands where nutritional deficiencies and poor water holding capacities become limiting and shallow duplex or heavy clays with poor physical structure and poor drainage. In heavy or shallow soils, roots develop poorly and the plants prematurely collapse from drought in spring.

L. albus prefers loamy soils with a higher natural fertility but are very sensitive to waterlogging. [5] Albus Lupin will perform better on higher pH soils than narrow-leaf lupin but will not tolerate soils with medium to high levels of clay.

Table 3: *Soil-type – Lupin species adaptation.*

Soil factor	Least adapted	Better adapted
Low pH (high Al)	*L. albus*	*L. angustifolius*
High pH (high HCO_3^-)	*L. angustifolius*	*L. albus*
Transient waterlogging	*L. albus*	*L. angustifolius*
Low fertility (sandy soils)	*L. albus*	*L. angustifolius*

Source: GIWA – Lupins.org

Photo 2: *Poor lupin establishment in non-wetting sands in Western Australia, 2011.*

Source: DAFWA.

5 Lupins.org

Heavy soils or clayed sands

Crusting of hard setting clays and red brown earth soils can cause lupin establishment problems. Avoid deep sowing and surface compaction after sowing. Stubble retention will assist in establishment by preventing compaction by rain before emergence. Deep ripping can benefit lupins in soils with hard pans and subsoil structure problems. [6]

Avoid deep gilgai or heavily contoured country

Contours and undulating country ('melon holes', 'crab holes' or gilgais) present two problems when growing pulses:

- Uneven crop maturity due to variation in soil water supply. Melon-holes usually store more water than the mounds, and the crop in wetter areas will often continue to flower and pod when the rest of the crop is already drying down. Similarly, contour banks retain more moisture after rain, and prolong crop maturity relative to the rest of the crop late in the crop.
- High harvest losses and increased risk of dirt contamination in the header sample. Many dryland pulse crops require the header front to be set close to ground level, and even small variations in paddock topography can lead to large variations in cutting height across the header front, and a significant increase in harvest losses.

Contamination of the harvested sample with dirt and clods is difficult to avoid in undulating, gilgai country, and can cause a significant increase in grading losses and costs.

MORE INFORMATION

Utilising soil biological processes to better manage water repellent soils

Non-wetting sands

Lupin does not grow well in non-wetting sands. The claying of non-wetting sands has dramatically improved the potential for lupin production on these soils, provided the clay applied is not too sodic or calcareous. Fortunately, this soil type is not common in the Northern region. [7]

1.1.2 Salinity

Key points:

- Soil salinity varies across the landscape and within paddocks.
- The severity varies over time, in response to both climate and land management.
- Soil salinity can be managed by farming actions.
- Lupins do not tolerate high levels of salinity.

What is soil salinity?

A saline soil is one that contains sufficient soluble salts (most commonly sodium chloride) that the growth of most plants is retarded, with damage occurring sooner in plants more sensitive to salt and much later in salt-tolerant plants such as saltbush. Salinity reduces a plant's ability to extract water from the soil, and specific ions in the salts can cause toxicity. A salinity outbreak is where symptoms of salinity are present.

Soils become saline via interaction with groundwater. If groundwater rises to within two metres of the soil surface, capillary action can bring water to the surface. When this happens, salts dissolved in the water are brought into the root zone, and when the water evaporates at the soil surface, concentrated salts are left behind.

Salinity affects crop yield and growth in dryland regions mainly by reducing Water Use Efficiency of crops through osmotic effect. Toxic effects of individual ions such as sodium can also cause yield reduction. When the osmotic pressure of the soil solution is less than (<) 700 kilopascals (kPa), there is a low rate of reduction in yield

6 W Hawthorne, W Bedggood (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

7 W Hawthorne, W Bedggood (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

irrespective of the type of ions (salt). At these lower osmotic pressures the specific ion effect, particularly of sodium, is significant.
For osmotic pressure greater than (>) 700 kPa the rate of crop yield reduction is severe. When the osmotic pressure is above 1,000 kPa, the crop yield is reduced by >50% and 80–95% of available soil water is not taken up by plants. [8]

Symptoms

What to look for in the paddock:

- Symptoms vary with soil salt concentration and severity of waterlogging.
- Poor crop and weed germination (except salt tolerant species) (Photo 3).
- Patches of apparently water-stressed or prematurely dead plants in areas subject to salinity in spring.
- Dry topsoils may be crusty possibly with salt crystals on the surface.

Photo 3: *Reduced emergence and smaller plants can die earlier in saline areas. Patches may also be wilted.*

Source: DAFWA

What to look for on the plant:

- Seeds swell but don't germinate or emerge, or seedlings die after emergence, particularly in drying soil.
- Wilted and dying plants in spring. Older leaves tend to wilt and die (Photo 4).

8 P Rengasamy (2006) GRDC Final Reports: UA00023 – Improving farming systems for the management of transient salinity and risk assessment in relation to seasonal changes in southern Australia. https://grdc.com.au/research/reports/report?id=531

- Roots may appear to be normal, but may be shallow and rot quickly after plant death.

Photo 4: *Older leaves shrivel and die.*

Source: DAFWA

Measuring salinity

Soil salinity varies across paddocks and farms, and vertically within the soil profile. Soil may be saline at depth but not in the topsoil. This situation indicates that there may be a future problem in the topsoil.

Soil samples can be taken to assess salinity by measuring the electrical conductivity (EC) of soil and water. EC is usually measured in dS/m). Distilled water has an EC of 0 dS/m, sea water has an EC of 35–55 dS/m, and the desirable limit for human consumption is 0.8 dS/m. Measurements may be taken instead of the electrical conductivity of a soil extract (ECe), of a water sample (ECw) and of irrigation water (ECiw) or drainage water (ECdw).

Dryland salinity

Dryland salinity occurs when naturally occurring salts in rocks and soil are mobilised and redistributed by water, e.g. by surface run-off after rain, the recharge of groundwater, subsurface lateral flows of groundwater, or groundwater discharge. It occurs throughout NSW (Photo 5). [9] Saline outbreaks in upland areas of the NSW Murray–Darling Basin cover around 62,000 hectares, but individual areas are usually less than 10 hectares. Most salt scalds occur in the 600–700 mm rainfall zone.

Photo 5: *Scalding by salt.*

Photo: Graham Johnson, NSW Government

Irrigation salinity

Irrigation salinity in NSW occurs mainly in southern NSW in the Murray and Murrumbidgee irrigation areas.

Areas of land affected by irrigation salinity have dropped sharply in the last 10 years (from 2015), from 14,000 hectares to less than 500 hectares in the Murray Valley. The mechanisms for this change are not completely understood, but are possibly due to a combination of reduced winter rainfall and better farm management and infrastructure.

Managing groundwater levels

Salinity management aims to maintain groundwater levels at least two metres below the soil surface, mainly by maximising the water plants use to reduce groundwater recharge. Useful techniques include:

- Monitoring groundwater levels.
- In low lying, non-production areas, growing species tolerant of salt and waterlogging.
- Growing perennial pastures, as they can use twice as much water as annual pastures.
- Do not grow lupins long fallows.
- Appropriate crop selection and crop rotations.
- Efficient irrigation management.

9 S Alt (2017) Salinity, New South Wales. Soilquality.org, http://soilquality.org.au/factsheets/salinity-nsw

MORE INFORMATION

[Improving farming systems for the management of transient salinity and risk assessment in relation to seasonal changes in southern Australia]

Troubleshooting

Recognising and acting on salinity problems early is the best solution, as salinity can be a more difficult and expensive issue to correct once it is well advanced. **Dryland salinity** outbreaks can be managed by excluding grazing on saline areas and sowing saline tolerant species. **Irrigation salinity** can be managed by improving irrigation management, specifically application efficiency. Specific management of salt-affected areas could include having hill and bed shapes that minimise salt accumulation around seedlings, and pumping and recycling groundwater (although this requires advice from a hydrology consultant). [10]

1.1.3 Sodic or dispersive soils

Sodicity is a term given to the amount of sodium held in a soil. Dispersive soils are generally a surface problem, sodicity can be at the surface but also at depth; i.e. plant roots hot this layer and become restricted in growth and cannot extract as much water out of the profile. High sodicity causes clay to swell excessively when wet. The clay particles move so far apart that they separate (disperse). This weakens the aggregates in the soil, causing structural collapse and closing-off of soil pores. For this reason, water and air movement through sodic soils is severely restricted. In crop paddocks, sodic layers or horizons in the soil may prevent adequate water penetration during irrigation, making the water storage low. Additionally, waterlogging is common in sodic soil, since swelling and dispersion closes off pores, reducing the internal drainage of the soil. Sodicity of the surface soil is likely to cause dispersion of surface aggregates, resulting in surface crusts.

Soils with an exchangeable sodium percentage (ESP) ≥6 are classified as sodic. Poor drainage, surface crusting, hardsetting (Photo 6) and poor trafficability or workability are common when the soil has a large proportion of sodium ions (Na^+), leading to reduced crop yield.

A surface crust is typically less than 10 mm thick and when dry can normally be lifted off the loose soil below. Crusting forces the seedling to exert more energy to break through to the surface, thus weakening it. A surface crust can also form a barrier reducing water infiltration.

Photo 6: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium; i.e. sodic soil.*

Source: Soilquality.org

Field research in Victoria/South Australia indicates that soil salinity and sodicity can substantially reduce crop yields. [11]

10 S Alt (2017) Salinity, New South Wales. Soilquality.org, http://soilquality.org.au/factsheets/salinity-nsw

11 Agriculture Victoria (2009) Chapter 4: Salinity and Sodicity. Subsoils Manual. http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_mgmt_subsoil_pdf/$FILE/BCG_subsoils_09_ch04.pdf

Crop growth is affected by salinity and sodicity in two ways: firstly, the osmotic potential effect and secondly specific ion toxicity. Salts lowers the osmotic potential (i.e. makes it more negative) or increases osmotic pressure leading to yield losses as plants cannot extract water from soils when soil solution has lower osmotic potential than the plant cell. The impact on grain productivity of rising electrical conductivity (EC) and ESP values at different depths is shown in Figure 1, which demonstrates that identifying the complete picture is essential to applying the management option.

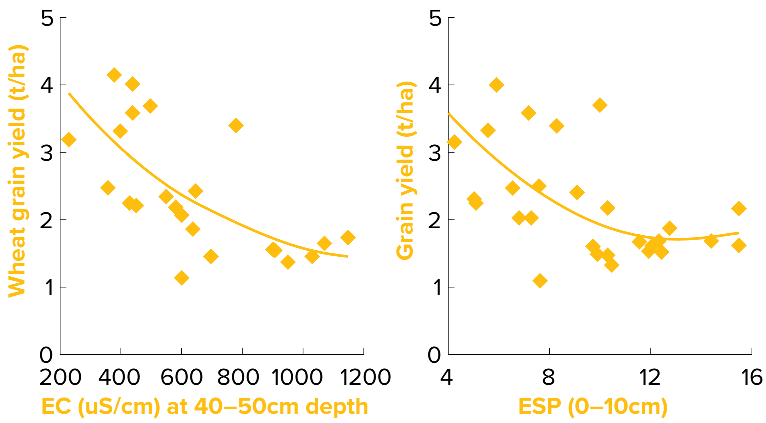


Figure 1: *Impacts of salinity and sodicity on productivity*

Source: Dalal et al. 2002 in GRDC

Sodic soils are prone to poor soil structure, particularly if the natural equilibrium between salinity and sodicity are out of balance. High salinity helps to counteract the effects of sodicity, but as described above, can cause yield issues. 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) and erosion. Gypsum application to these soils improves the soil structure facilitating leaching of salts, even under dry land conditions. Correcting cation imbalances requires providing a source of the 'good' cations, Ca2+ and/or Mg2+, which might come from gypsum, lime, 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 to observe results. It is also dependant on the pH of the soil.

The use of decision process models such as Gypsy© can be used as a guide when deciding on the cost of gypsum applications. [12]

Deep ripping

This can be used to break up compacted and poorly structured soils and to help generate structure and porosity. However, the benefits can be very short-lived. Sometimes deep ripping makes the soil worse because worked (tilled) soil disperses more readily. Ripping can bring up large clods of dispersive soil and bring toxic elements such as boron and salt to the surface. Consequently, only undertake deep ripping after careful consideration. If in doubt, first carry out deep ripping on a small test strip. After ripping apply gypsum or lime (in acid soils), preferably with additional organic matter, to help stabilise the deep ripped soil. A tramline (controlled traffic) farming system will help prevent re-compaction of the loosened soil. [13]

12 M Crawford (2015) GRDC Update Papers: Profit suckers – understanding salinity, sodicity and deep drainage. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Profit-suckers-understanding-salinity-sodicity-and-deep-drainage

13 T Overheu (2017) Management of dispersive (sodic) soils experiencing waterlogging. DAFWA. https://www.agric.wa.gov.au/water-erosion/management-dispersive-sodic-soils-experiencing-waterlogging

MORE INFORMATION

[Sodic soil management](#)

[Sodic soils a management labyrinth](#)

Lime application to sodic soils

Lime (calcium carbonate), like gypsum, is a compound containing calcium. Therefore, it can contribute to reducing the effects of sodicity. However, lime is relatively insoluble at a soil pH ($CaCl_2$) above 5. In most soils of the Murray and Murrumbidgee Valleys the pH ($CaCl_2$) is above 5, so lime is of little benefit. If the pH is below 5, lime will help to reduce both acidity and sodicity problems. A mixture of lime and gypsum may be a good option on sodic soils with a pH ($CaCl_2$) in the 5 to 6.5 range, to provide a more long-lasting effect than gypsum only. Again, soil tests and test strips are strongly recommended.

Cultivating sodic soils

dispersive and sodic soils are more prone to structural degradation than non-sodic soils. For this reason, they must be cultivated minimally and carefully. Excessive cultivation of these soils will cause major soil structure problems. In this may be evident as crusting, hardsetting and poor water penetration. [14]

1.1.4 Soil compaction

Soil compaction can limit crop growth. Subsoil compaction can reduce rooting depth of plants by slowing the rate of root penetration (Photo 7). This means roots are unable to access subsoil moisture and leachable nutrients such as nitrogen (N). This can result in poor nitrogen-use efficiencies. [15]

Photo 7: *A distinct compacted layer in a sandy loam. Note fractures in hard pan through which roots prefer to grow.*

Source: Soilquality.org

Deep ripping to reduce soil compaction

Key points:

- Deep ripping of compacted soils is most likely to improve grain yields on sandy soils and where compaction has occurred on upper parts of the soil profile through machinery traffic or livestock trampling.
- Deep ripping is less effective on heavy clay soils unless combined with gypsum on sodic soils prone to waterlogging.

14 NSW DPI (2009) Chapter D5. Sodic soil management. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/127278/Sodic-soil-management.pdf

15 Soilquality.org (2016) Optimising soil nutrition, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland

MORE INFORMATION

Deep ripping - Factsheet

Digging deep and controlling compaction

- Deep ripping will provide little benefit if other subsoil constraints such as salinity, sodicity or acidity are also present.
- Advances in machinery, such as 'slotting' and deep placement equipment to simultaneously introduce ameliorants at depth with ripping, could increase the financial and agronomic effectiveness of this approach to managing subsoil constraints.

Soil compaction can occur in many cropping soils and may be traffic or livestock induced or naturally occurring. By limiting the ability of crops to gain access to water and nutrients, soil compaction can reduce crop growth, grain yields and quality. Deep ripping involves disturbing the soil with strong, narrow tynes, below the normal cultivation layer, often up to 40 cm, without inverting the soil. By breaking up the soil, deep ripping can free the way for roots to penetrate the soil and access water and nutrients, leading to yield increases. However, it is only effective on certain soil types and is only likely to be financially viable when combined with strategies to ameliorate other subsoil constraints such as nutrient deficiency or toxicity, or sodicity. [16]

1.1.5 Soil pH

Lupin grows best in neutral to acidic soils. Narrow-leafed lupin is adapted to soils with a $pHCaCl_2$ of between 4.2 and 6.0 and will tolerate up to 20% exchangeable aluminium and high levels of exchangeable managanese. Albus lupin grows best in soils with a $pHCaCl_2$ of 4.6 to 7.0 and is tolerant of only moderate acidity (up to 8% exchangeable aluminium) but is more tolerant than canola or wheat.

High pH soils can be tolerated provided free lime is not present.

Sowing lupin on calcareous soil can reduce germination and result in seedling death and crop failure. Root growth of narrow-leafed lupin is more sensitive than that of albus lupin to high soil pH and free calcium carbonate. Root elongation of narrow-leafed lupin slows when the pH increases from 5.5 to 6.0. At a $pHCaCl_2$ greater than 6.0 the root surface can be damaged. Surface cells are peeled off and root hair formation slows. Shoot growth is also reduced in alkaline soils but is less sensitive than root growth.

High soil pH also impairs symbiosis with *Bradyrhizobium* rhizobia and reduces the number of nodules. Nodulation in albus lupin is more sensitive to high pH and free calcium carbonate than is nodulation in narrow-leafed lupin. [17] [18]

Acidic soil

Acidic soils are an impediment to agricultural production. More than half of the intensively used agricultural land in NSW is affected by soil acidity.

Acidity reduces the survival of Rhizobia and the effective infection of legume roots. When rhizobia are affected by soil acidity it shows as poor nodulation and results in reduced nitrogen fixation. Often Rhizobium bacteria are more sensitive to soil acidity than the host plant. Lime pelleting of inoculated legume seed is used to protect the inoculum against drying out and contact with fertiliser. Sowing into bands of limesuper also creates an environment suitable for survival of the inoculum in an acidic soil.

Management

If only the top 10 cm of the soil profile is acidic it can be readily corrected by applying and incorporating finely ground limestone. However, if acidification of the soil continues and the surface pHCa drops below 5.0 the acidity will leach into the subsurface soil (Figure 2). The further the acidity has moved down the profile the greater the effect on plant growth and the more difficult it is to correct. This is called subsurface soil acidity and is a long-term degradation of the soil.

16 GRDC (2009) Deep ripping – Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2009/06/grdc-fs-deepripping

17 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

18 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

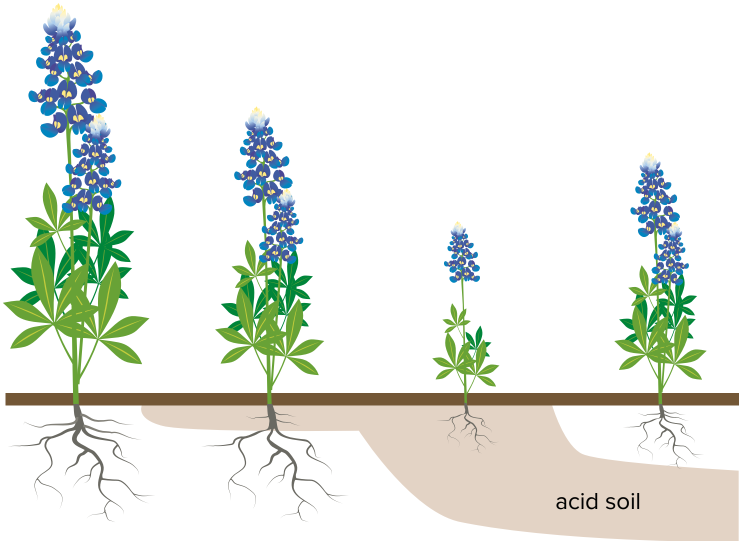


Figure 2: *The development of subsoil acidity and the implications for acid sensitive plants.*
a) No acidic soil problems
b) Acidification starts at the surface restricting surface root development.
c) Acidity is leached to depth when the pHCa of the surface soil drops below 5.0 and all root growth is restricted.
d) Subsurface soil acidity is permanent as surface applied lime only corrects acidity in the surface soil.

Source: NSW DPI

There are a number of agronomic practices to reduce soil acidification including; growing acid tolerant crops, reducing leaching of nitrate nitrogen, using less acidifying fertilisers and preventing erosion of topsoil. However, the most direct way of improving soil acidity is through liming.

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. The liming materials most commonly used are agricultural limestone and dolomite, but other materials are available.

Recommended liming rates based on a standard soil test are given in Table 4. Apply limestone before the most acid sensitive crop or pasture in a rotation as it gives the best economic return. If the limestone will not be effectively incorporated due to reduced tillage then apply the limestone a year before the most sensitive crop and apply it at a slightly heavier rate. These two actions will enhance lime movement into the top soil. The time of the year when lime is applied is not important. Limestone begins to become effective as soon as the soil is moist and reaches its major impact after 12–18 months.

Table 4: *Limestone required (fine and NV>95) to lift the pH of the top 10 cm of soil to 5.2. Colour codes group limestone rates to the nearest 0.5 t/ha.*

Soil test ECEC (meq/100 g)	Lime required (t/ha) to lift the pH of the top 10 cm:			
	from 4.0 to 5.2	from 4.3 to 5.2	from 4.7 to 5.2	from 5.2 to 5.5
1	1.6	0.8*	0.3*	0.2*
2	2.4	1.2	0.5*	0.4*
3	3.5	1.7	0.7	0.5*
4	3.9	2.1	0.9	0.6
5	4.7	2.5	1.1	0.7
6	5.5	3.0	1.2	0.8
7	6.3	3.3	1.4	1.0
8	7.1	3.8	1.6	1.1
9	7.9	4.2	1.8	1.2
10	8.7	4.6	1.9	1.3
15	12.5	6.7	2.8	1.9

*It is recognised that low rates of lime are impractical to apply, but over-liming can cause nutrient imbalances, particularly in these light soils.

KEY: Limestone rates per hectare

0.5 t/ha	1.0 t/ha	1.5 t/ha	2.0 t/ha	2.5 t/ha	3 to 4 t/ha	Split applications are advised

Source: NSW DPI

Because limestone moves very slowly down through the soil, incorporation should be to the depth of the acidity problem (or as deep as practicable) for the most effective and speedy response. [19]

Alkalinity

Alkaline soils occupy about 23.8% of total land area in Australia. More than 30% reduction in grain productivity occurs when the pH is above 9.0. When pH is more than 9, the soils are considered highly alkaline and often have toxic amounts of bicarbonate, carbonate, aluminium and iron. Nutrient deficiency is also likely to be a major problem and the high amount of exchangeable sodium in these soils reduces soil physical fertility. Lupin can tolerate mildly alkaline soils.

Management

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

Acidification to reduce pH below 9.0 can be reasonably achieved by growing legumes and the simultaneous application of gypsum. Gypsum will reduce sodicity and this can reduce alkaline pH to some extent. Growing legumes in crop rotation may help in sustaining any pH reduction. Reducing the soil pH below 9.0 enhances crop productivity in alkaline soils by avoiding the toxicity of aluminium and carbonates, nutrient deficiency and other possible microelement toxicity.

MORE INFORMATION

Soil acidity and liming

19 B Upjohn, G Fenton, M Conyers. (2005). Agfacts: Soil acidity and liming. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/167209/soil-acidity-liming.pdf

MORE INFORMATION

Chemistry and crop agronomy in alkaline soils

Making better liming decisions

Reducing soil alkalinity by applying these treatments can increase yield by 10–30%, providing economic benefits to farmers. [20]

Testing soil

Soil pH is a measure of the concentration of hydrogen (H +) ions in the soil solution, measured on a logarithmic scale from 1 to 14, with 7 being neutral (Figure 3). The lower the pH, the greater the acidity. A soil with a pH of 4 has 10 times more acid than a soil with a pH of 5, and 100 times more acid than a soil with a pH of 6.

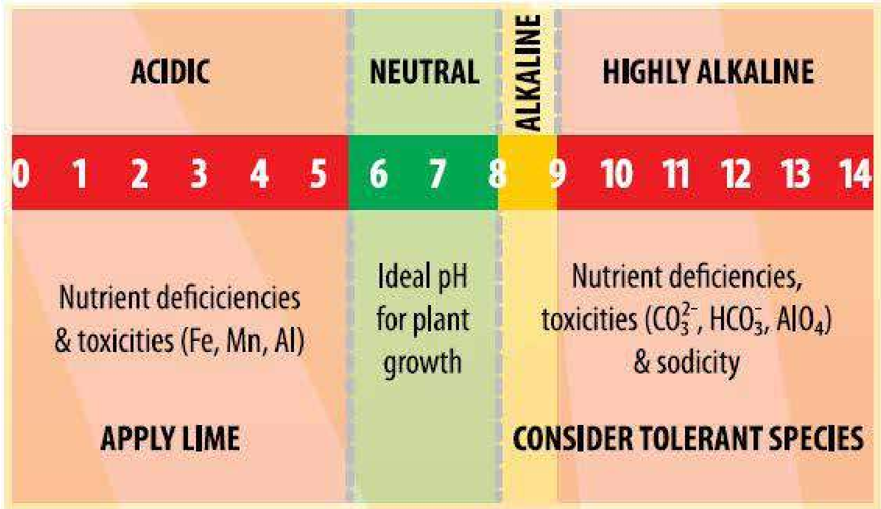


Figure 3: *Classification of soils on the basis of pH (1:5 soil:water), the implications for plant growth and some management options.*

Source: Soilquality.org

The standard measurement of soil pH uses a mixture of one part soil to five parts 0.01 M $CaCl_2$ (calcium chloride). Measured in water, pH can read 0.6–1.2 pH units higher than in calcium chloride, and soils with low total salts show large seasonal variation if pH is measured in water. Field soil pH kits give results similar to water measurements and complement periodic laboratory testing.

The best time to soil test is in autumn, two to ten days after good rain. Samples should not be taken from; overly wet or dry soils, at times of extreme high or low temperatures, within a few weeks of fertiliser applications, or within months of lime application. Sampling sites should take account of paddock variability and be recorded using GPS (Figure 11). Samples at the soil surface and subsurface will determine the soil pH profile and detect subsurface acidity. Sampling should be repeated at the same locations, same time of year and under similar conditions at least every three to four years to detect changes and allow adjustment of management practices. [21]

20 D Putnam, J Wright, L Field, K Ayisi (1992) Seed yield and Water Use Efficiency of white lupin as influenced by irrigation, row spacing, and weeds. *Agronomy Journal*, *84*(4), 557–563. P Rengasamy (2010) GRDC Final Reports: UA00092 – Chemistry and crop agronomy in alkaline soils. http://finalreports.grdc.com.au/UA00092

21 S Alt, P Gazey. (2013). Soil acidity – NSW. Soilquality.org. http://www.soilquality.org.au/factsheets/soil-acidity-new-south-wales

Photo 8: *Soil cores need to accurately reflect the main soil type in the paddock being tested.*

Photo: N Baxter, Source: GRDC

1.2 Paddock rotation and history

Key points:

- When planning rotations, potential and current agronomic limiting factors need to be considered. A break crop can only provide a break if it addresses one or more of these limiting factors.
- Continuous wheat crops are rarely as viable as rotations that include either a pasture or break crop.
- Rotations help spread the risk of the enterprise being affected by economic and natural challenges.
- Break crops can increase Water Use Efficiency in the following cereal crop.
- Modern farming techniques can influence the value or need for break crops in some situations.
- In all rotations sound agronomy is the key to success.

The costs attributed to a break crop can make it appear unprofitable, however, in reality the control of grass weeds and increase in nitrogen in a legume crop is going to have a long-term benefit across subsequent cereal crops. It is often better to compare the gross margins of a sequence of crops to capture the costs and benefits of the break crop. Lupins are one of the legume crops that can be sown prior to canola, providing additional stored nitrogen and water for the canola crops and a two-year disease and weed break.

The previous crop should preferably have been a cereal resulting in low soil nitrogen and disease levels for pulses. Lupins grow and yield better after cereals than after pasture. Cereal yields are higher after lupins than after pasture. On infertile soils or after high yielding lupin crops, cereals grown after lupins will still need nitrogen Fertiliser applications. Pasture production is also better after lupins than after cereals, particularly on infertile sands.

Growing successive lupin crops is not recommended because of the risk of disease, particularly Pleiochaeta. Where close cropping of lupins is intended, remove as much lupin stubble as possible to ensure less disease is carried through, treat the seed with a fungicide, leave cereal stubble to cover the ground and direct drill.

Choose paddocks at low risk of bitter lupin contamination. Bitter contamination of sweet albus is irreversible, and contaminated seed must be replaced for sowing. Bitter contamination of sweet crops may compromise markets and may lead to rejection of deliveries. Growers are strongly advised not to plant bitter albus in the main growing areas for sweet albus. [22]

For more information, see Section 2 Pre-planting, Section 2.3.3 Bitterness in albus lupin.

1.3 Lupin in crop rotation

Lupin has many advantages in both cropping and mixed cropping–livestock farming systems (Table 5). The value of lupins is not determined just by the return from the harvested grain; factors such as the disease break for following crops, nitrogen fixation by lupins and the value of stubble and lupin grain for stock feed must be considered, or the profitability of lupins will be underestimated. It is therefore important to look at lupins in rotation with other crops and not in isolation.

22 W Hawthorne, W Bedggood (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

Table 5: *Benefits and disadvantages of sowing lupin in a cropping sequence.*

Benefits of including lupin	Disadvantages of including lupin
It can be used to extend cereal crop rotations by acting as a break crop (non-host) for cereal diseases. Significant nitrogen contribution for subsequent crops Improved soil structure Alternative weed control options to delay or reduce the incidence of herbicide resistance. A high protein grain that can be valuable as part of a profitable livestock enterprise. Providing cash income - although the price of the grain is often lower compared with other pulses, the value to the growth of subsequent crops is often greater. Offering a cheap, less erosion prone alternative legume to peas where soils are suitable. Being the only pulse crop suited to acidic sandy soils. Often increased yields of cereals following lupins, in particular on sandy soils. Wheat yields and protein levels are increased when grown after lupins. Can be crop topped to prevent herbicide resistant weeds setting seed. Lupin can increase the Water Use Efficiency (WUE) of subsequent crops. Early trials found that the WUE in the lupin-wheat was consistently at least three kg/ha/ mm greater than for a wheat-wheat rotation. Lupin seed stores much better than cereals and are more resistant to insect attack. This is one of the advantages of lupin grain, where if market prices are poor, they can be stored for a long period of time until prices increase again. This is common practice amongst growers in the Northern region.	There must be long breaks between lupin crops and large distances between lupin paddocks due to its vulnerability to disease and contamination from bitter lupin. Mice infestations can be a big issue for farmers, with both the sowing and flowering stages targeted as a food source. Lupins do not tolerate free lime (up to 4%) and will grow poorly on hard setting or shallow (< 25 cm) soils. They do not tolerate waterlogging Large losses can occur if lupin incur frost damage. Lupins can be prone to insect damage. Manganese deficiencies can result in split seed disorder. Harvesting lupin can be difficult due to pod shattering. Diseased lupin stubble can cause lupinosis in grazing stock. Marketing lupin can be difficult.

MORE INFORMATION

Impact of crop rotations on profit, nitrogen and ryegrass seed bank in crop sequences in southern NSW.

1.4 Fallow weed control

Summer (short) fallows are important to conserve moisture and nutrients for the following crop. The benefits of a fallow are only attained when the weeds in the fallow are controlled.

Fallows are an inherent part of farming in lower rainfall areas. The main function of a fallow is to conserve moisture and nutrients for the following crop. Fallows can also reduce the carryover of disease and the number of weeds into the next crop. The benefits of a fallow are only attained when the weeds in the fallow are controlled

(Photo 9). Fallows can be used as an Integrated Weed Management (IWM) tool to target cropping weeds such as annual grasses. [23]

Photo 9: *Clean summer fallows (left) prevent soil moisture being lost to weed growth (right).*

Photo: B Collis, Source: GRDC and DAFWA

Consideration of likely broadleaf weeds is essential. Pay special attention to stopping seed set of broadleaf weeds in the years prior to a lupin crop, or choose paddocks with low broadleaf weed burdens. Adequate weed control measures must be taken during the previous year and again before sowing, particularly to address problem weeds. [24]

Germination and early growth of lupin can be affected by the allelopathic effects of camel melon residue (Photo 10), so melon control in the summer before growing lupin is essential. [25]

Photo 10: *Trials of lupin affected by the allelopathic effects of camel melons that were breaking down.*

Photo: Barry Haskins, in NSW DPI

1.4.1 Herbicides

Herbicides are currently the main weed control option in fallows, with glyphosate the most commonly used herbicide. There are a range of herbicides that can be used in fallow and it is important to rotate the herbicide mode of action used. Fallows managed with a single herbicide mode of action have seen a species shift towards more herbicide tolerant weeds. Herbicide mixtures with different modes of action should be used for weed control in fallow to control a broader range of weed

23 A Johnson, R Thompson. Weed control for cropping pastures in central west NSW. Chapter 5: Fallows. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/154723/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-5.pdf

24 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

25 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

species. Weed control in summer can be difficult as weeds grow very quickly. Weeds are most susceptible to herbicides in the two- to four-leaf stage which can occur within 14 days of germinating rain. [26]

For some soil-active broadleaf herbicides to be fully effective, or to avoid crop damage, application must only occur when there is sufficient soil moisture and the soil surface is level. Herbicides applied before seeding or split between pre and post-sowing can be safer than post-sowing if the soil will be left ridged (e.g. after using knife points). [27]

1.4.2 Cultivation

Weed control in fallows may require a cultivation under certain conditions (Photo 11). Considering a cultivation does not mean returning to old techniques and machinery. For example, a shallow cultivation can be used to control seedling weed growth under hot, dry and dusty conditions when herbicides are generally not as effective. A strategically targeted cultivation is also a very effective IWM tool, especially when used in rotation with herbicides to prevent a build-up of herbicide tolerant weeds. Combining herbicide use with cultivation also reduces the risk of degrading the soil structure and increasing erosion through excessive cultivation. At the end of a long fallow which has been managed with herbicides, a shallow cultivation can be useful. This cultivation, about eight weeks prior to sowing, can be used to stimulate weed emergence of dormant weed seed if large numbers of seed are known to be present. These weeds can then be controlled prior to sowing. This technique, sometimes referred to as an 'autumn tickle' is a useful technique for reducing the soil seed bank and delaying the development of herbicide resistant weed populations. [28]

Photo 11: *Lupin fits well in minimum tillage, direct drilling, no-tillage or zero-tillage farming systems provided the physical seeding process is not affected.*

Source: GRDC

MORE INFORMATION

GRDC Strategic Tillage Tips and Tactics fact sheet.

26 A Johnson, R Thompson. Weed control for cropping pastures in central west NSW. Chapter 5: Fallows. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/154723/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-5.pdf

27 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

28 A Johnson, R Thompson. Weed control for cropping pastures in central west NSW. Chapter 5: Fallows. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/154723/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-5.pdf

VIDEOS

WATCH: GCTV5: Managing summer fallow.

WATCH: Burning for weed and snail control.

MORE INFORMATION

Weed control for cropping and pastures, Chapter 5: Fallows.

1.4.3 Burning stubble on a short fallow

Research has found that while burning standing stubble temperatures were often hot enough to destroy annual ryegrass seed but not wild radish seed on the soil surface. Wild radish required 500˚C for 10 seconds; annual ryegrass only required 400˚C for the same period.

Burning can also help to control snail infestations.

Photo 12: *A paddock of burnt stubble where a pulse crop was later sown at a property in Armatree about 100 kilometres north of Dubbo in northern New South Wales.*

Photo: S Cowley, Source: GRDC

Burning windrows (higher concentration of material) can produce temperatures that are hot enough for a sufficient period to kill wild radish seed on the soil surface. [29]

For more information, see Section 6: Weed control.

1.5 Fallow chemical plant-back effects

Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing winter crops. Many herbicide labels place time and/or rainfall restrictions on sowing certain crops and pastures after application, due to potential seedling damage. Crops such as pulses and legume pastures are the most sensitive to herbicide residues (Photo 13). [30]

29 A Johnson, R Thompson. Weed control for cropping pastures in central west NSW. Chapter 5: Fallows. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/154723/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-5.pdf

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

Photo 13: *Group B herbicide damage in narrow-leafed lupin. Discoloured leaflets develop brown necrotic spots on the edge and tips and then slowly die.*

Source: DAFWA

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

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

The following points are especially relevant:

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

Keeping accurate records of all herbicide treatments and planning crop sequences well in advance, can reduce the chance of crop damage resulting from herbicide residues. [31]

The following plant-back periods are a guide only based on label recommendations (Table 6). The time indicated between application and safe crop rotation intervals will 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, and 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. [32]

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

32 G Brooke, C McMaster (2016) Weed control in Winter crops 2016. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops

Table 6: *Guidelines for crop rotations – Fallow commencement/maintenance and pre-sowing seedbed weed control*

Lupins	Specific Details	Herbicide Group	
9mo	pH 5.6–8.5	B	Ally®
7d	<0.5 L/ha	I	Amicide® Advance (700 g/L)
14d	0.5–0.98 L/ha	I	
21d	0.98–1.5 L/ha	I	
7d	140 g/ha	I	Cadence®
14d	200 g/ha	I	
21d	400 g/ha	I	
		B	Eclipse® 100 SC
7d	<0.51 L/ha	I	LV Ester 680 (680 g/L)
14d	0.51–1.0 L/ha	I	
21d	1.0–1.6 L/ha	I	
-		B	Express®
		B	Flame®
-		I	Garlon™
		G	Goal®
-	NNSW 0.2 L/ha	I	Grazon™ Extra
-	NNSW 0.3 L/ha	I	
-	NNSW 0.4 L/ha	I	
-	NNSW 0.6 L/ha	I	
24mo	SNSW <0.5 L/ha	I	
-	NNSW <750 mL/ha	I	Hotshot™
20mo	SNSW <500 mL/ha	I	
7d	0.20 L/ha	I	Kamba® 500
14d	0.28 L/ha	I	
21d	0.56 L/ha	I	
	NNSW <0.0375 L/ha	I	Lontrel™ Advanced 600 g/L
	NNSW 0.0375–0.15 L/ha	I	
	NNSW >0.15 L/ha	I	
9mo	SNSW <0.15 L/ha	I	
12mo	SNSW <0.15–0.25 L/ha	I	
24mo	SNSW >0.25 L/ha	I	
7d	250–500 mL/ha	GI	Pyresta®
14d	900 mL/ha	GI	
-	0.225 L/ha	I	Starane™
-	0.45 L/ha	I	
-	0.9 L/ha	I	
1hr	9–26 g/ha	G	Sharpern® WG
1hr	30 g/ha	G	Terrain™ 500WG
		M	Weedmaster® Argo™

MORE INFORMATION

[Weed control in Winter crops]

[Herbicide residues and weed control]

*Goal® herbicide at up to 75 mL/ha may be safely applied 1 day prior to planting lupins.
*Susceptible crops should not be sown for at least 2 years when LontrelTM Advanced at more than +++0.15 L/ha has been used in northern Australia.
*Weedmaster® Argo® - Do not disturb weeds by cultivation, sowing or grazing for 6 hours of daylight following treatment of annual weeds and 7 days for perennial weeds.

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

1 = 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.
2 = When applied to dry soils at least 15 mm of rain must fall prior to the commencement of the plant-back period.
3 = 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 plant-back intervals should be extended to 21 days.
4 = Black cracking clays. During drought conditions the plant-back period may be significantly longer.
5 = Additional rainfall requirements need to be observed – see label.
6 = 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.
7 = Plantback refers to rapeseed not canola.
8 = Soil pH determined by 1:5 soil:water suspension method.

Source: NSW DPI, 2017

1.5.1 Conditions required for breakdown

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

Risks

In those areas that do not experience conditions which will allow breakdown of residues until just prior to sowing, it is best to avoid planting a crop that is sensitive to the residues potentially present on the paddock, and opt for a crop that will not be affected by the suspected residues. In most cases, cereals or canola would be better options as these crops are comparatively less affected by herbicide residues. If dry areas do get rain and the temperatures become milder, then they are likely to need substantial rain (more than the label requirement) to wet the sub-soil, so the topsoil can remain moist for a week or more. This allows the microbes to be active in the top-soil where most of the herbicide residues will be found. Sensitive crops include legume pastures (e.g. clovers, Lucerne, or forage legumes) and pulse crops (eg. lupins, lentils, fieldpeas, faba beans, or vetch). [33]

For more information, see Section 6: Weed control.

1.6 Seedbed requirements

Ensure early paddock preparation to enable timely sowing. Lupin crops should ideally be sown into a moist seedbed to ensure good even establishment and nodulation. Lupins can suit a wide range of sowing conditions and can be successfully direct drilled so long as correct seed depth is maintained.

Preparation of a seedbed to ensure good seed soil contact is an important element in successful crop germination and establishment. Lupins can be successfully direct-drilled where the soil is sufficiently friable to give good seed to soil contact.

The increased risk of rhizoctonia with direct drilling can be reduced by a three-week weed free period before sowing, and by using cultivating tynes at seeding that cultivate deeper than the sowing depth. At least one working or soil disturbance before seeding could be desirable on sandy soils where rhizoctonia is a frequent problem. Carefully check soil moisture is adequate for direct drilling or reduced tillage, especially on non-wetting soils. [34]

Because lupin (particularly albus) has large cotyledons that are pushed above the ground during germination, they have difficulty emerging through the soil if it is

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

34 W Hawthorne, W Bedggood (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

compacted or if they are sown too deep. Therefore, seed placement is very important for good establishment. This can be helped by using press wheels. High stubble loads can also reduce seed–soil contact, causing uneven or poor establishment. [35]

However, cereal stubble can provide protection for lupin seedlings. Direct drilling lupin into cereal stubble is a successful crop establishment method. This is important on sandy soils where wind erosion may be a problem and the lupin plant may suffer from wind blasting. Stubble can help to reduce splash of brown spot spores. Stubble also conserves soil moisture and reduces aphid infestations, which minimises virus infection and transfer. [36]

Minimum or zero tillage is highly suitable for lupins. [37]

1.7 Soil moisture

MORE INFORMATION

Improving soil moisture

Moisture is a key limitation on the productivity of soil.

Three main factors affect soil moisture content:

1. how well your soil can absorb water;
2. how well your soil can store moisture; and
3. how quickly the water is lost or used.

Although these factors are strongly determined by the proportions of clay, sand and silt, good soil management also plays a critical role. [38]

1.7.1 Dryland

Sowing systems that retain stubble help to reduce evaporation losses from the soil. Retaining stubble or plant residue from previous crops also protects the soil from erosion, reduces soil moisture loss and assists in crop growth and height.

Stubble retention

Key points:

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

Historically, stubble has been burnt in southern and central New South Wales because it creates easier passage for seeding equipment, enhances seedling establishment of crops, and improves control of some soil-borne diseases and herbicide resistant weeds. However, the practice of burning stubble has recently declined due to concerns about soil erosion, loss of soil organic matter and air pollution. Stubble is increasingly being retained (without burning practices) which has several advantages of soil fertility and productivity. Summer rainfall and warmer conditions promote decomposition of stubble. In northern NSW over half of the original cereal stubble may be decomposed by winter sowing time, compared to southern NSW where much more of the residue remains in place.

Lupin is best direct drilling into standing cereal stubble (Photo 14).

35 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

36 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

37 W Hawthorne, W Bedggood (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

38 G Reid. (2004). Improving soil moisture. Agnote DPI – 494. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/166796/improve-soil-moisture.pdf

Photo 14: *Lupin sown into standing cereal stubble.*

Source: Pulse Australia

At Wagga Wagga, NSW after 21 years of a wheat-lupin rotation in a no-till system where stubble was either burnt or retained, the annual rate of change (loss) of total soil nitrogen was -13 kg/ha/year for retained stubble and -28 kg/ha/year for burnt stubble. The difference (15 kg/ha/year) is the result of retaining stubble compared with burning stubble. Any advantage of retained total nitrogen would not all be available to the plant, but can be seen as a long-term benefit in retained stubble systems in conserving rather than accumulating nitrogen.

The long-term average grain yield of wheat was 3.4 t/ha with an average stubble yield post-harvest of 7.7 t/ha (range 2.5 to 11.2 t/ha). The quantity of post-harvest stubble after lupins was 6.1 t/ha (1.5 to 15.8 t/ha) (Table 7). [39]

Table 7: *Grain and stubble yields, with derived harvest indices, for lupins (27 seasons) from a long-term experiment at Wagga Wagga, New South Wales.*

Lupins									
Grain yield	0.4	0.8	1.2	1.6	2	2.4	2.8	3.2	3.6
Stubble yield	3.4	4.3	5.2	6.1	7.0	7.9	8.7	9.6	10.5
Harvest index	0.11	0.16	0.19	0.21	0.22	0.23	0.24	0.25	0.25

Source: NSW DPI

Reducing erosion risk

One of the main benefits of stubble retention is reduced soil erosion. Retaining stubble decreases erosion by lowering wind speed at the soil surface and decreasing runoff. At least 50% or more ground cover is required to reduce erosion. It is generally considered that 50% ground cover is achieved by 1 t/ha of cereal stubble, 2 t/ha of lupin stubble and 3 t/ha of canola stubble. The study at Wagga Wagga, NSW (mentioned above) demonstrated that stubble retention reduced soil losses by almost two thirds compared to burnt paddocks. It also increased infiltration of rainfall.

39 B Scott, C Podmore, H Burns, P Bowden, C McMaster (2013) Developments in stubble retention in cropping systems in southern Australia. Report to the GRDC. NSW DPI.

VIDEOS

WATCH: Stubble Management.

WATCH: GCTV15: Stubble height Pt. 1.

and Stubble height Pt. 2.

WATCH: GCTV4: Burning for stubble retention.

MORE INFORMATION

Wide row pulses and stubble retention

Stubble retention in south-eastern Australia

Increasing soil water content

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

Increasing soil carbon

Retaining stubble increases the input of carbon to soil. Stubble is approximately 45% carbon by weight and represents a significant input of carbon to soil. It can take decades for retaining stubble to increase the amount of soil organic carbon. After 10 years, stubble retention generated 2 t/ha more soil organic carbon than stubble burnt plots to a depth of 10 cm in a red chromosol during cropping trials with ley pasture rotations at Wagga Wagga. [40] After 25 years the inclusion of a clover pasture in the rotation in the same trial had a greater effect on soil organic carbon increases even with tillage compared to stubble retention. [41] Retaining stubble may only increase soil carbon where it is coupled with cultivation but not with direct drilling.

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

Other benefits of stubble retention

Retaining stubbles returns nutrients to the soil, the amounts depend on the quality and quantity of stubble. Wheaten stubble from a high yielding crop may return up to 25 kg of available nitrogen per hectare to the soil. The addition of organic matter with retained stubbles supports soil life, and can improve soil structure, infiltration and water holding capacity. These benefits are greater when integrated no till practices.

Benefits of leguminous stubble retention

Leguminous stubbles provide slow release nitrogen. Subsequent non-leguminous crops may however need additional nitrogen fertiliser to optimise crop production and/or overcome microbial nitrogen tie-up in soil when commencing stubble retention practices, especially if combined with reduced tillage. Grain or pasture legumes included in a cropping sequence are an economic option for nitrogen fertilisation, but require sufficient available phosphorus for efficient nitrogen fixation especially in clay soils.

Stubble and fungal diseases.

Fungal diseases can be carried from one crop to the next in several ways. It is important to consider the life cycle requirements of any pathogen in order to control it effectively. Some fungal diseases are harboured in stubbles, while others are predominantly present in root residues in the soil. Burning stubble is often of limited benefit because it does not affect pathogens beneath the soil surface. Effective weed management of other host species may be more important, or rotations with non-host plants. However, yield losses from Brown leaf spot and cucumber mosaic virus in lupins have been reduced by retention of stubble. [42]

40 B Scott, P Eberbach, J Evans, L Wade (2010) Stubble retention in cropping systems in Southern Australia: Benefits and Challenges. NSW Industry & Investment and Charles Sturt University.

41 K Chan, M Conyers, G Li, K Helyar, G Poile, A Oates, I Barchia (2011) Soil carbon dynamics under different cropping and pasture management in temperate Australia: Results of three long-term experiments. Soil Research **49**: 320–328

42 J Carson, K Flower (2013) Benefits of retaining stubble NSW. Soilquality.org. http://soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

1.7.2 Irrigation

Even in relatively high and reliable rainfall areas, natural rainfall patterns may not match the water requirements of many commercial crops. Efficient use of irrigation water means more crop can be grown for a given volume of water, an important factor now that water supplies are becoming limited and expensive. Efficient irrigation reduces operating costs because less water has to be pumped for a given yield. Inefficient irrigation can lead to water and nutrients draining through the root zone, which is a waste of water and fertilisers and leads to rising and contaminated water tables.

Lupin is not often sown in irrigated farming operations in the Northern growing region.

1.8 Yield and targets

It is important for growers to be able to predict yields and targets of their crops. Seed yield from a lupin crop is determined by the amount of seed produced per unit area. Albus lupin averages 5–15% higher yields than narrow-leaf lupin under high rainfall conditions (Figures 4 and 5). [43]

Mean Yield t/ha		6.51	4.10	3.73	3.28	2.78	2.23	1.80	1.26	0.83	0.46
Max Error %	All Trials	1	1	3	2	3	2	3	2	1	1
Variety / Trials		1	2	2	10	12	14	9	7	2	1
PBA Jurien	34	98	100	100	102	104	103	106	106	97	136
PBA Gunyidi	57	103	98	105	103	103	103	101	105	91	99
Mandelup	60	102	105	101	105	101	104	102	100	100	60
PBA Barlock	45	99	101	106	100	101	101	101	101	94	122
Jenabillup	60	100	103	106	103	100	98	96	106	93	87
Quilinock	59	94	102	97	99	98	93	95	103	95	114
Coromup	8	100	94	92	94	96	95	94	94	104	94
Wonga	60	94	98	98	92	94	91	87	83	88	97
Danja	18	90	101	82	88	88	84	86	86	117	89
Jindalee	60	94	96	95	90	89	84	74	78	80	49

Figure 4: *NVT Long Term Results (2008–15) for narrow-leaf lupins in the south east of the southern NSW cropping zone. Yields are presented as a percentage of the site mean yield.*

Source NVT Online.

Mean Yield t/ha		6.97	3.93	3.21	2.84	2.25	1.75	1.30	0.81	0.43
Max Error %	All Trials	0	0	0	0	0	0	0	0	0
Variety / Trials		1	4	10	5	16	10	9	6	1
Luxor	62	99	103	102	106	103	104	103	105	128
Rosetta	62	106	100	104	101	102	99	100	106	104
Ultra	62	94	100	97	102	97	99	100	99	110
Kiev Mutant	62	93	98	96	104	93	94	98	102	115

Figure 5: *NVT Long Term Results (2008–15) for albus lupins in the south east of the southern NSW cropping zone. Yields are presented as a percentage of the site mean yield.*

Source: NVT Online

Yield results from Pulse Breeding Australia (PBA) and National Variety Trials (NVT) are available from the NVT website, as well from the specific Pulse Variety Management Package (VMP) brochure.

The three components influencing lupin yield are:

1. number of pods per square metre (pod density)

MORE INFORMATION

A pulses update for southern NSW 2017

43 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

2. number of seeds per pod
3. seed weight.

The yield components develop in sequence, although there is some overlap.

Pod density

Pod density is a function of the number of plants and the number of lateral branches, which sets the number of flowering spikes. Growth before pod initiation influences the potential number of pods through its effect on the number of leaves, which influences the number of potential sites for flowering branches in the leaf axils. Final pod density is controlled by water availability (and therefore assimilate supply) before and during flowering. Although pod number is usually set by the end of flowering, pods can be aborted up to maturity. High plant populations tend to produce plants with fewer branches and a greater number of pods on the main stems. As a result, a greater proportion of the yield is derived from the pods on the main stem.

Number of seeds per pod

The potential number of seeds per pod ranges from three to six, depending on the location on the plant. As branch order increases up the plant, the number of seeds per pod decreases. Seed set is determined mainly by temperature and moisture during flowering, both of which affect assimilate supply. Pollination and fertilisation generally do not limit the potential number of seeds per pod. There is a correlation between total dry matter production at flowering and seed density.

Weight per seed

Seed weight is the last component to be set, and is the least variable. It is largely determined by the genetic potential of the variety. The two additional impacts on seed weight are the location of the pod on the plant and the timing and severity of environmental stress. Seeds are generally smaller on the later-order laterals. [44]

1.8.1 Estimating yield

To estimate a lupin crop yield:

1. Count the number of plants in 1m of row in five locations in the paddock and then calculate the number of plants per square metre by multiplying the number of plants per metre of row by the factor corresponding to the crop row spacing (Table 8).
2. Determine the total number of seeds per square metre by using the numbers already determined above:
   Total seeds/m^2 = average no. pods per plant × average no. seeds per pod × no. plants per m^2
3. Calculate estimated yield

Table 8: *Conversion factors for determining number of plants per square metre.*

Row Spacing	Factor	Row Spacing	Factor
15 cm (6in.)	6.7	25 cm (10in.)	4
17.5 cm (7in.)	5.7	30 cm (12in)	3.3
20 cm (8in.)	5	40 cm (15.7in)	2.5
22.8 cm (9in.)	4.4	50 cm (19.6in.)	2

Source: NSW DPI

MORE INFORMATION

Estimating crop yields and crop losses

44 J Walker, K Hertel, P Parker, J Edwards (2011) Lup5inLupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

1.8.2 Harvest index

Lupin has a lower harvest index than other pulse crops such as peas, chickpeas and lentils. This is because lupin has higher vegetative biomass. In lupin, the weight of the pod wall itself makes up a much greater percentage of the total pod weight at maturity than in other pulses such as soybean. This also contributes to a low harvest index. A low harvest index can also result from a low plant population. If the plant population is low, the lupin puts more resources into vegetative growth, resulting in a lower harvest index. [45]

1.8.3 Seasonal outlook

Queensland

The Monthly climate statement, which interprets seasonal climate outlook information for Queensland, is produced by the Science Delivery Division of the Queensland Department of Science, Information Technology and Innovation (QDSITI). The statement is based on QDSITI's own information and draws on information from national and international climate agencies.

The QDSITI assessment of rainfall probabilities is based on the current state of the ocean and atmosphere and its similarity with previous years. In particular, QDSITI monitors the current and projected state of El Niño–Southern Oscillation (ENSO), referring to information such as Variation of sea-surface temperature from average and the Southern Oscillation Index (SOI). Based on this information, QDSITI uses two systems to calculate rainfall probabilities for Queensland:

- QDSITI's SOI-Phase system produces seasonal rainfall probabilities based on phases of the SOI.
- QDSITI's experimental SPOTA-1 (Seasonal Pacific Ocean Temperature Analysis version 1) monitors Pacific Ocean sea-surface temperatures from March to October each year to provide long-lead outlooks for Queensland summer (November–March) rainfall.

Outlooks based on both the SOI-Phase system and SPOTA-1 are freely available, although a password is required to access the experimental SPOTA-1 information (email: rouseabout@dsiti.qld.gov.au). [46]

Queensland Alliance for Agriculture & Food Innovation produces regular, seasonal outlooks for grain producers in Queensland. These high-value reports are written in an easy-to-read style and are free.

New South Wales

The Seasonal Conditions Report is issued each month by NSW Department of Primary Industries. It contains information on rainfall, water storages, crops, livestock and other issues. It is available to landholders to help them make informed decisions on how they manage operations, and prepare for seasonal conditions and drought.

Seasonal Conditions Reports are also used by the Regional Assistance Advisory Committee in making recommendations to the NSW Government on potential support for farm businesses, families and communities. [47]

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

45 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

46 QDSITI (2016) Seasonal climate outlook. Queensland Department of Science, Information Technology and Innovation, https://www.longpaddock.qld.gov.au/seasonalclimateoutlook/

47 NSW DPI. Seasonal conditions reports. NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/climate-and-emergencies/droughthub/information-and-resources/seasonal-conditions

as heat sums, soil water and soil nitrate, and well as ENSO status. It is designed for decision makers such as farmers whose businesses rely on the weather.

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

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

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

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

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

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

As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation. [48]

MORE INFORMATION

Climate Kelpie: Decision support tools for managing climate

1.8.4 Fallow moisture

For a growing crop, there are two sources of water: the water stored in the soil during the fallow, and the water that falls as rain while the crop is growing. Growers have some control over the stored soil water; i.e. measuring soil moisture before sowing. 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 it is needed. [49]

Plant available water capacity

A key determinant of potential yield in dryland agriculture is the amount of water available to the crop, either from rainfall or stored soil water. In the Northern region, the contribution of stored soil water to crop productivity for both winter and summer cropping has long been recognized. The amount of stored soil water influences decisions to crop or wait (for the next opportunity or long fallow), to sow earlier or later (and associated variety choice) and the input level of resources such as nitrogen fertiliser.

The amount of stored soil water available to a crop - Plant Available Water (PAW) – is affected by pre-season and in-season rainfall, infiltration, evaporation and transpiration. It also strongly depends on a soil's Plant Available Water Capacity (PAWC), which is the total amount of water a soil can store and release to different crops. The PAWC, or 'bucket size', depends on the soil's physical and chemical characteristics as well as the crop being grown.

Information regarding the PAW at a point in time, particularly at planting, can be useful in a range of crop management decisions. Estimating PAW, whether through use of a soil water monitoring device or a push probe, requires knowledge of the PAWC and/or the Crop Lower Limit (CLL).

48 MCV (2014) Australian CliMate—climate tools for decision makers. Managing Climate Variability R & D Program, https://climateapp.net.au/

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

A wide variety of soils in the Northern region have been characterised for PAWC and the characterisations are publicly available in the APSoil database, which can be viewed in Google Earth and in the 'SoilMapp' application for iPad.

The field-based method for characterising PAWC has been tried and tested across Australia, but users need to be mindful of common pitfalls that can cause characterisation errors. Knowledge of physical and chemical soil properties like texture or particle size distribution and (sub) soil constraints helps interpret the size and shape of the PAWC profiles of different soils. It can also assist in choosing a similar soil from the APSoil database.

Extrapolating from the point-based dataset to predict PAWC at other locations of interest is a challenge that needs further research. Preliminary analyses drawing on soil landscape mapping (NSW) and land resource area (LRA) mapping (Queensland) suggest that an understanding of position in the landscape and the story of its development may assist with extrapolation. This is because in many landscapes the soil properties determining PAWC are tightly linked to a soil's development and position in the landscape and these same aspects underpin soil and land resource surveys.

While the concept of using soil-landscape information to inform land management is not new (e.g. Queensland land management manuals draw on the same concept), the availability of these maps on-line makes them more accessible and assists with visualising a location's position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors

Uncertainty of PAWC estimates translates into uncertainty in PAW. The extent to which this affects potential decision making depends on the question asked, but also needs to be viewed in terms of the spatial variability in PAW and the accuracy of the method to convert this water into a yield forecast.

Factors that influence PAWC

An important determinant of the PAWC is the soil's texture. The particle size distribution of sand, silt and clay determines how much water and how tightly it is held. Clay particles are small (< 2 microns in size), but collectively have a larger surface area than sand particles occupying the same volume. This is important because water is held on the surface of soil particles which results in clay soils having the ability to hold more water than a sand. Because the spaces between the soil particles tend to be smaller in clays than in sands, plant roots have more difficulty accessing the space and the more tightly held water. This affects the amount of water a soil can hold against drainage (DUL) as well as how much of the water can be extracted by the crop (CLL).

The effect of texture on PAWC can be seen by comparing some of the APSoil characterisations from the Northern region. The soil's structure and its chemistry and mineralogy affect PAWC as well. For example, subsoil sodicity may impede internal drainage and subsoil constraints such as salinity, sodicity, toxicity from aluminium or boron and extremely high density subsoil may limit root exploration, sometimes reducing the PAWC bucket significantly.

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth. Some APSoil characterisations only determined the CLL for a single crop. [50]

HowWet?

HowWet? is a program developed by APSRU that uses records from a nearby weather station to estimate how much plant available water has accumulated in the soil and the amount of organic N that has been converted to an available nitrate during a fallow. *HowWet?* tracks soil moisture, evaporation, runoff and drainage on a

MORE INFORMATION

Methods and tools to characterise soils for plant available water capacity (Coonabarabran)

50 K Verburg, B Cocks, T Webster, J Whish (2016) GRDC Update Papers: Methods and tools to characterise soils for plant available water capacity (Coonabarabran). https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Methods-and-tools-to-characterise-soils-for-plant-available-water-capacity-Coonabarabran

daily time-step. Accumulation of available N in the soil is calculated based on surface soil moisture, temperature and soil organic carbon.

HowWet?:

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

This information aids in the decision about what crop to plant and how much N fertiliser to apply. Many grain growers are in regions where stored soil water and nitrate at planting are important in crop management decisions. 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 the soil type on my farm and local rainfall to date, what is the relative soil moisture and nitrate-N accumulation over the fallow period compared with most years? Relative changes are more reliable than absolute values.
- Based on estimates of soil water and nitrate-N accumulation over the fallow, what adjustments are needed to the N supply?

Inputs:

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

Outputs:

- a graph showing plant-available soil water for the current year and 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 OC 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. [51]

1.8.5 Water Use Efficiency

Water Use Efficiency (WUE) 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.

WUE relies on:

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

Water Use Efficiency in lupin crops is lower than in cereal crops (Table 9). The process of fixing nitrogen requires more energy and therefore uses more water. Lupin also has a high protein content in its seed. Plants need more energy to produce 1

51 MCV (2012) How Wet/N? Managing Climate Variability R & D Program, https://climateapp.net.au/

g of protein than to produce 1 g of carbohydrate. Protein production also requires more nutrients, and therefore water. Lupin does have some adaptations to make it more water-use efficient. Lupin has been bred to flower early and set pods and seeds before the onset of moisture stress. Early flowering also leaves more time and moisture available for use after flowering. This results in larger seeds, and improved Water Use Efficiency and harvest index. [52]

Table 9: *Water Use Efficiency based on total biomass (WUEdm) or grain yield (WUEgy) of different crops. Water Use Efficiency is based on the biomass or yield per mm of crop water use. Values are mean and range.*

Crop	WUEdm	WUEgy
	(kg/ha.mm)	
Lupin	17.3 (9.3–22.3)	5.1 (2.3–8.3)
Canola	24.0 (17.1–28.4)	6.8 (4.7–8.9)
Chickpea	13.7 (9.4–18.1)	3.2 (2.1–5.2)
Wheat	36.1 (21.2–53.1)	15.9 (9.2–23.2)

Source: GRDC

Lupin can also improve the WUE of subsequent crop rotations. In Western Australia, growing wheat after lupins increased total water use by 11% (168 mm compared to 186 mm) and Water Use Efficiency by 26% (10.0 kg/ ha/mm compared to 7.9 kg/ha/mm) compared to continuous wheat.

Water is the principal limiting factor in rain-fed cropping systems in northern Australia. The objective of rainrain 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.

In the north of the Northern grains region, rainfall is more summer-dominant and 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. In the south of the region, rainfall is winter-dominant.

Storing water in fallows between crops is the grower's most effective tool to manage the risk of rainfall variability, as in-season rainfall alone, in either summer or winter, is rarely enough to produce a profitable crop, especially with high levels of plant transpiration and evaporation.

Fortunately, many cropping soils in the Northern grains region have the capacity to store large amounts of water during the fallow. [53]

Definitions and calculation of aspects of WUE are as follows:

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

52 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

53 GRDC (2009) Water Use Efficiency fact sheet. Grains Research and Development Corporation, https://grdc.com.au/__data/assets/pdf_file/0029/225686/water-use-efficiency-north.pdf.pdf

VIDEOS

WATCH: GCTV12: Water Use Efficiency initiative.

WATCH: GRDCTV10: Grazing stubbles and Water Use Efficiency.

MORE INFORMATION

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

Strategies to increase yield

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

1. Increase the amount of water available to a crop (e.g. good summer weed control, stubble retention, long fallow, sowing early to increase rooting depth).
2. Increase the proportion of water that is transpired by crops rather than lost to evaporation or weeds (e.g. early sowing, early N, vigorous crops and varieties, narrow row spacing, high plant densities, stubble retention, good weed management).
3. Increase the efficiency with which crops exchange water for carbon dioxide to grow dry matter; i.e. transpiration efficiency (e.g. early sowing, good nutrition, 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).

The last three of these all improve WUE. [54]

1.9 Disease status of paddock

Lupins are susceptible to a wide range of diseases. Roots, hypocotyls, stems, leaves, pods and seeds of lupin are all subject to infection by disease organisms (Photo 15). Several of these diseases have the capacity to cause catastrophic losses, but this is rare if management guidelines are followed.

Photo 15: *Brown spot lesions affecting lupin leaves.*

Source: DAFWA

Key steps in the integrated management of lupin diseases include crop rotation, stubble management, fungicide or pesticide application, variety selection, seed testing and soil testing.

54 J Hunt, R Brill (2012) Strategies for improving Water Use Efficiency in western regions through increasing harvest index. GRDC Update Papers, April 2012, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0018/431280/Strategies-for-improving-water-use-efficiency-in-western-regions-through-increasing-harvest-index.pdf

1.9.1 Soil testing for disease

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

PreDicta B

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

PreDicta B is a DNA-based soil testing service that identifies which soilborne pathogens pose a significant risk to broadacre crops prior to seeding.

PreDicta B includes tests for:

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

Access PreDicta B testing service

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

SARDI processes PreDicta B samples weekly from February to mid-May (prior to crops being sown) every year.

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

1.9.2 Cropping history effects

If a paddock has a history of lupin disease or in areas with high disease risk, it is recommended that growers allow a four year break between lupin crops.

For more information, see Section 9: Diseases.

1.10 Nematode status of paddock

Pratylenchus thornei and *Pratylenchus neglectus* (RLN) are migratory root endoparasites that are widely distributed in the grain growing regions of Australia and can reduce grain yield by up to 50% in many current susceptible varieties. *P. thornei* is the most damaging species and occurs commonly in the northern part of the Northern grain region; *P. neglectus* occurs less frequently than *P. thornei* but is common in the southern part of the Northern region.

1.10.1 Nematode testing of soil

PreDicta B should be used to test soil to nematodes prior to sowing.

For more information, see Section 1.9.1 Soil testing for disease, above.

The Queensland Government also has a service: Test your farm for nematodes.

1.10.2 Effects of cropping history on nematode status

Lupin is resistant to *P. thornei* and *P. neglectus*. Lupin can help to reduce nematode populations in infected paddocks.

For more information, see Section 8: Nematodes.

1.11 Insect status of paddock

Lupin crops are more prone to insect damage than cereal crops and need to be checked at critical periods for insects.

- Emergence – 3 weeks; Red legged earth mite, cutworm, lucerne flea, snails and slugs.
- Flowering; Aphids, mirids.
- Pod Fill; Native budworm (Photo 16).

Photo 16: *Native budworms damaging lupin pods.*

Source: IPM Guidelines

1.11.1 Insect sampling of soil

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

- Monitor crops frequently so as not to be caught out by new or existing pests.
- Look for and report any unusual pests or damage symptoms—photographs are useful.
- Just because a pest is present in large numbers in one year does not mean it will be so the next year. Another spasmodic pest, e.g. soybean moth, may make its presence felt.
- However, be aware of cultural practices that favour pests and rotate crops each year to minimise the build-up of pests and plant diseases. [55]

Sampling methods

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

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

Soil sampling by spade

Method:

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

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, use of the type of seed that is to be sown as a crop is likely to indicate the species of pests that could damage that crop. The major disadvantage of the germinating-grain bait method is the delay between the seed placement and assessment. [56]

Useful tools

GrowNotes™ Alert is a free nationwide system for delivering urgent, actionable and economically important disease, pest, weed and biosecurity issues directly to you, the grower, adviser and industry body, the way you want. Real-time information from experts across Australia, to help growers increase profitability.

A GrowNotes™ Alert notification can be delivered via SMS, email, web portal or via an App for your smart devices. There are also three by dedicated regional Twitter handles – @GNAlertNorth, @GNAlertSouth and @GNAlertWest – that can also be followed.

PIRSA Insect diagnostic services: The South Australian Research and Development Institute (SARDI) Entomology Unit provides an insect identification and advisory service. They identify insects to the highest taxonomic level for species where this is possible. They can also provide biological information and guidelines for control. SARDI has a collection of approximately 5,000 species of pests and beneficial insects. This collection helps provide rapid and reliable identification of most insects.

1.11.2 Effect of cropping history

It is important to consider paddock history when planning for pest management. Resident pests can be easier to predict by using paddock history and agronomic and weather data to determine the likely presence (and numbers) of certain pests within a paddock. This will point to the likely pest issues and allow growers to implement preventive options. [57] Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil moisture retention, groundcover and soil biology and this has also affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity but also create more favourable conditions for many pests such as slugs, earwigs, weevils, beetles

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

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

MORE INFORMATION

[Pest Genie Australia](#)

[APVMA.](#)

and many caterpillars. In turn, they have also influenced beneficial species such as carabid and ladybird beetles, hoverflies and parasitic wasps. [58]

Where paddock history, paddock conditions or pest numbers indicate a high risk of pest damage, a grower might decide to use pre-seeding control measures to reduce pest pressure, apply a seed dressing to protect the crop during the seedling stage, and plan to apply a foliar insecticide if pest numbers reach a particular level. [59]

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 buildup.
- Insect numbers decline during a clean long fallow due to lack of food.
- Summer cereals followed by volunteer winter crops promote the buildup 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-till encourages beneficial predatory insects and earthworms.
- Incorporating stubble promotes black field earwig populations.
- False wireworms are found under all intensities of cultivation but numbers decline if stubble levels are very low.

Soil insect control measures are normally applied at sowing. Because different insects require different control measures, the species of soil insects must be identified before planting. Soil insects are often difficult to detect as they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the moist–dry soil interface. [60]

See Section 7: Insect control, for more information.

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

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

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

Pre-planting

Key messages

- In variety choice, consider yield and adaptation to the area, disease resistance, grain quality, marketability, and proximity to receival point.
- A soil test should be used to determine soil pH before choosing a lupin variety to plant in a paddock.
- Be aware of the specific management needs for the variety chosen through its variety specific management package (VSMP). [1]
- Only use lupin seed that is free of disease.
- Test for seed quality in terms of germination, vigour and disease prior to sowing. Only sow the highest quality seed (Figure 1).
- If using grower retained seed, ensure that it has been stored correctly; i.e. at the right moisture and temperature and for no longer than 12 months.

Photo 1: *Malformed and broken lupin seeds and seedling. Germination percentage and vigour is low in damaged seed.*

Source: DAFWA

2.1 Varietal performance and ratings yield

Select lupin varieties depending on yield potential for your environment and resistance to diseases that cause regular problems in your area. For characteristics and yield potential of different varieties, refer to Table 1.

1 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

Table 1: *Lupin variety characteristics and reaction to diseases.*

Variety	Flowering time	Pod loss, shatter resistance	Lodging resistance	Seed size (g/100 seeds)	Disease: Brown leaf spot	Disease: Pleiochaeta root rot	Disease: Phomopsis stem infection	Disease: CMV # seed transmission	Disease: BYMV #	Disease: Anthracnose resistance	North: Yield as a % of MandelupⒹ 2012–2016: East 1.68 t/ha	North: Trial no.	North: West 2.18 t/ha	North: Trial no.	South: Yield as a % of MandelupⒹ 2012–2016: East 2.32 t/ha	South: Trial no.	South: West 1.00 t/ha	South: Trial no.
Narrow-leaf																		
JenabillupⒹ	early	G	MG	14	MR	R	MS	MS-MR	MR	MS	88	3	91	9	96	35	94	4
JindaleeⒹ	mid–late	G	G	13	MR	MR	R	SS	S	MS	82	3	78	9	84	35	82	4
MandelupⒹ	very early	G	MP	14	MS	R	R	MS	MS	MR	100	3	100	9	100	35	100	4
PBA BarlockⒹ	early	VG	G	13	MS	R	MR	MR	MS	R	96	3	97	9	100	32	101	4
PBA GunyidiⒹ	very early	VG	G	13	MS	R	R	MS–MR	MS–MR	MR	109	3	95	9	102	35	94	4
PBA JurienⒹ	Early	G	G	13	MS	R	R	MS-MR	MS	R	102	3	99	9	102	28	102	4
Quilinock	early	G	MP	16	MS	R	MS–MR	MR	–	VS	80	3	89	9	93	34	94	4
WongaⒹ	early–mid	G	MG	13	MS	S	R	R	MS	R	86	3	89	9	91	35	93	3
Albus											Yield as a % of LuxorⒹ 2012–2016: East 1.90 t/ha	Trial no.	West 1.96 t/ha	Trial no.	Yield as a % of LuxorⒹ 2012–2016: East 2.44 t/ha	Trial no.	West t/ha	Trial no.
Kiev Mutant	very early	G	G	35	R	VS	R	Immune	n.d.	VS	102	3	103	6	94	33	–	–
LuxorⒹ	early	G	G	35	R	R	R	Immune	n.d.	VS	100	3	100	6	100	33	–	–
RosettaⒹ	mid	G	G	35	R	MR	R	Immune	n.d.	VS	96	3	93	6	98	33	–	–
Ultra	very early	G	G	35	R	S	R	Immune	n.d.	VS	103	3	102	6	95	33	–	–

Yield results are a combined across sites analysis using NVT, NSW DPI and PBA yield trials from 2012–2016.
# = Data from Pulse Breeding Australia
n.d. = no data.
Lodging, pod loss and shattering resistance
MP = Moderately poor
MG = Moderately good
G = Good
Disease resistance
VG = Very good
VS = Very susceptible
S = Susceptible
MS = Moderately susceptible
MR = Moderately resistant
R = Resistant
Source: NSW DPI

2.1.1 Narrow-leaf lupin

JenabillupⒹ

A Released in 2007 by the Western Australian Department of Agriculture and Food (DAFWA). High yielding, medium–tall, early flowering variety. JenabillupⒹ has moderate resistance to Bean yellow mosaic virus (BYMV) infection. BYMV can cause significant damage in eastern states when seasons are suitable, such as in 2014. Jenabillup⑴ has performed very well in NSW. Jenabillup⑴ has moderate resistance to anthracnose and is intolerant of metribuzin herbicide. It is also moderately susceptible to phomopsis stem infection. Commercialised by Seednet, protected by PBR. An End Point Royalty (EPR) of $2.53/tonne applies.

Jindalee⑴

Jindalee⑴ is the latest flowering and maturing variety currently available. It is suited to early sowing in higher rainfall districts where its vernalisation (cold requirement) prevents it from flowering too early. It is suited to situations of bulky dense canopies that would otherwise lead to poor pod set in other varieties. Jindalee⑴ can benefit from late spring rains. Jindalee⑴ anthracnose rating is MS, this level is generally adequate if combined with seed testing, paddock monitoring and sound crop hygiene management. Jindalee⑴ is R to phomopsis and is MR to brown leaf spot. Jindalee⑴ has speckled seed and medium seed alkaloid levels. Seed is available through Seednet.

Mandelup⑴

Released in 2004 by DAFWA. High yielding, early maturing variety with good early vigour. Suited to the low–medium rainfall zones of NSW. Has a tendency to lodge in very high productivity situations and not generally recommended for the higher rainfall zones. Mandelup⑴ is the earliest maturing variety currently available and therefore the most suitable for crop topping. Marketed by Heritage Seeds, protected by PBR. An EPR of $2.53/tonne applies.

PBA Barlock⑴

Released in 2013 by Pulse Breeding Australia (PBA) in Western Australia, to replace Mandelup⑴ and Tanjil in all WA lupin-growing zones. Compared with Mandelup⑴, PBA Barlock⑴ is slightly later flowering and maturing, but has a shorter harvest height. It is moderately resistant to lodging in high rainfall regions and is more resistant to pod shattering than Mandelup⑴. Resistant (R) to anthracnose. Tolerant to metribuzin (equal to Mandelup⑴). Moderately resistant (MR) to phomopsis stem blight. Commercialised by Seednet, protected by PBR. An EPR of $2.75/tonne applies.

PBA Gunyidi⑴

Released in 2011 by PBA in Western Australia, as a replacement for all varieties in the medium and low rainfall zones of WA. PBA Gunyidi⑴ has superior resistance to pod shatter and good lodging resistance, allowing later harvest without incurring significant shatter losses. Resistant (R) to phomopsis stem blight. Moderately resistant (MR) to anthracnose. Tolerance to the herbicide metribuzin is equivalent to Mandelup⑴, but is more susceptible to damage from Eclipse®. Commercialised by Seednet, protected by PBR. An EPR of $2.75/tonne applies.

PBA Jurien⑴

Released in 2015 by PBA in Western Australia. PBA Jurien⑴ is a broadly adapted high yielding variety that is R to anthracnose, phomopsis and grey spot. It is tolerant to metribuzin (superior to PBA Barlock⑴) with early flowering and maturity similar to other current varieties. NSW trials have shown it to be more susceptible to plant lodging than other current varieties in high rainfall areas, particularly when sown early and when conditions suit high biomass levels. Commercialised by Seednet, protected by PBR. An EPR of $2.75/tonne applies.

Wonga⑴

Wonga⑴ is an early-mid flowering, moderate yielding lupin released from NSW. It is moderately tall and vigorous and stands erect. Wonga⑴ is R to anthracnose and phomopsis. It is MS to brown leaf spot. Wonga⑴ has speckled seed and medium seed alkaloid levels. It matures slightly slower than Mandelup⑴. Wonga⑴ has moderate resistance to premature wilting on duplex soils with shallow underlying clay.

2.1.2 Albus lupin

Old standard varieties, Kiev Mutant, Ultra and Hamburg were outclassed around a decade ago by two new varieties bred by the GRDC supported lupin breeding program at the Wagga Wagga Agricultural Institute of the NSW Department of Primary Industries. The varieties Luxor⏀ and Rosetta⏀ have higher yield and better disease resistance. [2]

Luxor⏀

Released in 2005 by NSW DPI. Higher yielding than Kiev Mutant or Ultra. Resistant to pleiochaeta root rot (the cause of many seedling deaths in older varieties). Luxor⏀ is seven days later flowering than Ultra, but earlier flowering than its sister line Rosetta⏀. Suited to the medium–low rainfall zones of NSW. Commercialised by Seednet, protected by PBR. An EPR of $3.08/tonne applies. Released in 2005 by NSW DPI. Higher yielding than Kiev Mutant or Ultra in longer season environments.

Rosetta⏀

Rosetta⏀ is moderately resistant (MR) to pleiochaeta root rot (less resistant than Luxor⏀, much better than Kiev Mutant, slightly better than Ultra). Later flowering and taller than Luxor⏀, it is especially suited to higher rainfall areas. Commercialised by Seednet, protected by PBR. An EPR of $3.08/tonne applies.

MORE INFORMATION

Hart Bros. Seeds – Albus lupins

2.1.3 Lupin breeding

The lupin industry in Australia is based largely on Lupinus angustifolius, the narrow-leafed lupin. This species was developed as a new crop in Australia by J S Gladstones in the 1960s from semi-domesticated L. angustifolius introduced from Europe. Breeding since that time has focussed on developing disease resistance, and concurrently yield and quality. All new varieties must contain less than 0.02% alkaloids on average. The greatest challenge facing breeders is the urgent need for anthracnose resistance. [3]

The Department of Agriculture and Fisheries Western Australia and the GRDC have co-invested in the breeding and commercial release of lupin varieties for the past 20 years. In 2016, Australia's largest plant breeding company, Australian Grain Technologies (AGT), added lupins to its grains breeding portfolio. The licensing arrangement will allow AGT, as the licensee, to commercially develop the germplasm developed through these combined breeding activities as well as invest directly in improved new varieties. The GRDC will continue to support lupin development through pre-breeding and systems agronomy investments. [4]

2.2 Lupin for stock feed

There are two ways lupins are used in livestock production:

- grain is fed specifically to livestock as a supplement to maintain or increase liveweight and
- stubble is grazed after harvest.

2.2.1 Lupin grain for stock feed

Lupins are widely used as a source of protein and energy in livestock feeds (Table 2). Their high protein content makes them a valuable resource for monogastric and ruminant production systems as they are cost competitive with a wide range of other protein sources. Their low levels of starch and high levels of fermentable

2 K Penfold (2006) Ground Cover Issue 64: Push to lift albus lupins in NSW. GRDC. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-64/Push-to-lift-albus-lupins-in-NSW

3 W Cowling, J Gladstones (2000) Lupin breeding in Australia. In *Linking Research and Marketing Opportunities for Pulses in the 21st Century* (pp. 541–547). Springer Netherlands.

4 S Watt (2016) Ground Cover Issue 122: AGT brings lupins into its fold. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-122-May-Jun-2016/AGT-brings-lupins-into-its-fold

carbohydrate make them a highly desirable ruminant feed due to the low risk of acidosis.

Lupin seed stores well and so it is often kept as a feed ration during drought. Because they are large seeded, stock can easily find seed and little is left to waste.

The comparatively high levels of soluble and insoluble non-starch polysaccharides can influence the utilisation of other nutrients in lupins and hence they must be used strategically if livestock production responses are to be optimised.

Lupins also store well, are easy to handle and are readily accepted by most stock. They are largely free of anti-nutritional factors such as trypsin inhibitors, lectins and saponins. In monogastrics the complex carbohydrate profile is the main constraint to use as it influences the net energy yield, and has been shown to affect the utilisation of other nutrients in the diet.

Lupin can also increase the ovulation rate of ewes, with research finding that lupin supplementation for a period as short as six days prior to ovulation increases ovulation rates.

Although lupins are relatively high in protein, the biological value of the protein is limited by a relatively low in methionine and lysine. However, low levels of methionine and lysine are of little or no consequence to ruminants where the protein is mostly ruminant fermented. In pig and poultry diets these shortfalls can be made up from other proteins or synthetic amino acids.

Removing the hull improves the value of lupins for monogastrics and fish, but inclusion rates of kernel meal into pig and poultry diets is limited by the level of non-starch polysaccharide.

The hull fraction from many commercial operations still has a protein content of 8% and can be pelleted for ruminant rations.

When compared with soybean meal, lupins have significant advantages:

- A concentrated source of both protein and energy;
- A lack of any major anti-nutritional factors (e.g. trypsin inhibitors);
- No requirement for heat treatment; and
- Desirable handling and storing attributes due to the robust seed coat.

MORE INFORMATION

The effect of lupin supplementation on superovulatory response and embryo recovering in merino ewes.

Table 2: *Nutrient and energy values of the three lupin species (whole seed).*

	L. angustifolius	*L. albus*	*L. luteus*
Crude fibre (%)	15.4	10.6	16.3
ADF (%)	19.7	14.6	24.9
NDF (%)	23.5	17.6	34.3
Calcium (%)	0.2	0.2	0.2
Phosphorus (%)	0.3	0.36	0.43
Alkaloid (%)	0.02	0.02	0.04
DE Pigs (MJ/kg)	14.6	16.9	16.4
ME Cattle (MJ/kg)	12	11.9	n/a
ME Sheep (MJ/kg)	12.2	12.5	n/a
AME Poultry (MJ/kg)	10.4	13.2	11.4

Source : Petterson et al, (1997) in Lupin.org

MORE INFORMATION

Lupins.org – Feed and Food

Table 3: *Analysis of lupin whole seed and kernels.*

Species	L. angustifolius		L. albus		L. luteus		L. mutabulis	
	whole seed (%)	kernel (%)	whole seed (%)	kernel (%)	whole seed (%)	kernel (%)	whole seed (%)	kernel (%)
Seed Coat	24	0	18	0	27	0	16	0
Moisture	9	12	9	11	9	12	8	10
Protein	32	41	36	44	38	52	44	52
Fat	6	7	9	11	5	7	14	17
Ash	3	3	3	4	3	4	3	4
Lignin	1	1	1	1	1	1	1	1
Polysaccharides	22	29	17	21	8	11	9	10
Oligosaccharides	4	6	7	8	9	12	5	6
Minor components	0.50	1	0.60	1	0.90	1	1	1

Source: GIWA – Lupins.org

Table 4: *Comparison of Australian Sweet Lupin varieties for protein, oil, seed weight and alkaloids.*

Variety	Seed Weight	Protein	Oil	Alkaloid
Merrit	100	100	100	100
Mandelup⁽ᐟ⁾	105	95	100	116
Belara	106	92	108	88
Danja	104	97	104	168
Kalya	99	97	96	145
Quilinock	112	98	94	80
Tallerack	100	102	93	37
Tanjil	99	96	108	122
Coromup	120	109	100	127

(% of Merrit which typically has seed weight = 145mg; protein = 36% dry weight basis; oil = 7% dry weight basis; alkaloid = 0.012%

Source: DAFWA – Lupins.org

2.2.2 Lupin stubble for stock feed

Benefits

Lupin stubbles are reasonably nutritious and can achieve daily weight gains up to 200 and 500 grams per head in lambs and young cattle respectively. Lupin seed is very nutritious and can produce rapid weight gains. Livestock performance is mainly driven by the quantity of available seed and any green material in the paddock. Broad-leaf lupin grain is nearly three times larger than narrow leaf and thus easier for livestock to find, causing increased daily intakes and production. Different parts of the lupin plant vary greatly in quality. Table 5 lists the differences between leaf, stem, grain and pod for narrow-leaf lupins. Seed pods can maintain liveweight as long as protein is available from other parts of the diet such as seed. Livestock performance is better if higher value components of the stubble are available. The more stubble there is, the greater the likely availability of these components.

Table 5: *Feed quality of the components of narrow leaf lupin stubble before and after grazing.*

	Crude protein (%)		Dry organic matter digestibility (%)	
	3 December	24 March	3 December	24 March
Stem	3.7	3.9	31.68	17.46
Leaf	19.6	10.9	29/61	31.59
Pods	3.1	3.3	51.66	23.31
Seed	33.2	32.5	78.93	80.73

Source: May, Barker and Ferguson (1990) Performance of weaner steers grazing stubbles of Narrow Leafed Lupin and Wheat stubbles. Proceedings Australian Society of Animal Production, Vol 18 Page 288–291

Risks

A potential issue with grazing lupin stubble or in some cases feeding lupin seed is the risk of lupinosis, a disease that primarily damages the liver and causes loss of appetite, poor production and sometimes death. Lupinosis is caused by a toxin that is produced by the fungus Diaporthe toxica, formerly known as Phomopsis leptostromiformis. The fungus can infect all plant parts but is more commonly seen on dry stems at maturity and on pods and in some cases seed. It is commonly referred to as phomopsis stem and pod blight, or simply phomopsis. Some lupin varieties are resistant to infection by Diaporthe, which means lower risk of lupinosis for livestock in normal years. With careful grazing management the risk is small and the benefits are great. In years with late season rain or hail, the risk of lupinosis increases. Sowing lupins close to the previous year's stubble also increases the risk.

Grazing management of stubble to reduce the risk of lupinosis

The key to lowering the risk of lupinosis if the infection status of stubbles is unknown is to reduce the need for livestock to graze lupin stems as they are likely to contain higher levels of toxin. To achieve this, ensure that there is sufficient lupin grain and green weeds available. Livestock naturally select this higher quality feed and when it runs out they are then forced to eat lower quality portions such as pods and stem material. Graze lupin stubbles as soon as possible after harvest, as fungal growth and the toxin tend to increase once the plant dies and losses its resistance. The longer grazing is delayed the greater the risk that rain will promote fungal growth. In long hot dry summers the risk is much lower and grazing can be delayed to take advantage of the ability of grain to hold its quality later into the season. Avoid moving hungry livestock onto lupin stubbles. Wait until mid morning after animals have had a chance to graze.

Stubble management

Practices that encourage rapid breakdown of infected stubble will reduce the potential risk of lupinosis. Infected stubble can be burnt or incorporated into the soil to aid rapid breakdown. In no-till situations, inspect stubble for pycnidia development before grazing is allowed. In seasons with summer rain, stubble must be inspected frequently. [5]

2.3 Planting seed quality

Key points:

- All seed should be tested for quality including germination (high germination – above 80%) and vigour (AA test). Seed should also be tested for bitterness. Use large, graded seed.

MORE INFORMATION

Reducing the risk of lupinosis and the incidence of phomopsis

5 R Crowley, G Casburn (2013) Reducing the risk of lupinosis and the incidence of phomopsis. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/478243/Reducing-the-risk-of-lupinosis-and-the-incidence-of-phomopsis.pdf

- If grower retained seed is of low quality then consider purchasing registered or certified seed from a commercial supplier and always ask for a copy of the germination report.
- Careful attention should be paid to the harvest, storage and handling of grower retained seed intended for sowing.
- Calculate seeding rates in accordance with seed quality (germination, vigour and seed size). [6]

Seed quality at sowing can have a major impact on crop performance and resulting yield at the end of the season - particularly in pulse crops. Seed size, quality and germination varies between varieties, from year to year, from paddock to paddock and should be checked for each seed line to be used.

Always use high quality seed. Lupin seed, like other pulse seeds, is susceptible to weathering impacts and mechanical damage at harvest. Loose seed coats and split, fractured or broken seeds reduce the germination percentage and can affect seedling vigour.

Test any retained seed for germination, vigour and disease. Do not keep seed from severely diseased crops.

Check the seed analysis certificate for germination percentage and purity before purchase. Legislation requires that only the minimum germination test must be supplied on the label with certified seed. Be sure to ask for the seed analysis certificate and any disease testing for the seed lot being purchased.

A number of seed-borne viruses, including cucumber mosaic virus (CMV) can affect lupin. Where possible, use seed that has been tested and certified free of viruses.

If seed is coming from WA or SA (and now NSW) it must be tested for Lupin anthracnose, a disease caused by fungal infection (resulting in deformed growth). In 2016 lupin anthracnose was reported for the first time in NSW crops. Growers should be on high alert for the disease.

Though many of the newer varieties of lupin have better disease resistance, it is still a good idea to have seed tested for cucumber mosaic virus (CMV) and Anthracnose. [7]

Seed quality is important for good establishment. Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if the seed is undamaged, stored correctly and from a plant that has had adequate nutrition (Photo 2).

6 Pulses Australia. Chickpea Production: Southern and Western region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

7 Agriculture Victoria (2017) Growing lupin. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-lupin

Photo 2: *A normal (left) and abnormal (right) narrow-leafed lupin seedling. Growth deformity occurs when poor quality seed is used; e.g. weather damaged, poor storage or diseased. Note the missing cotyledon and deformed shoot on the abnormal lupin.*

Photo: Di Holding, Source: NSW DPI

Effect of poor quality seed on yield

Often, seed quality problems only emerge if the crop is not harvested under ideal moisture or seasonal finishing conditions. A sharp seasonal finish, a wet harvest or delayed harvest can have a big impact on seed quality.

Using severely weather damaged or mechanically damaged seed will result in:

- Poor establishment and poor crop performance.
- Reduced plant vigour (increased susceptibility to soil-borne pathogens during establishment and increased susceptibility to foliar pathogens).
- Patchy, uneven plant stands (increased susceptibility to weed competition, aphids and viruses).
- Uneven plant development complicating in-crop management (e.g. herbicide applications).
- Uneven and delayed crop maturity (e.g. making desiccation timing difficult and leading to a mixed grain sample).
- Lower yields from a combination of all of the above

As a general guide, weather damaged seed with lower than normal germination and vigour levels should only be sown under very good conditions (for rapid establishment) and at a higher seeding rate. Such seed is not recommended for deep sowing or moisture seeking. [8]

Grower retained seed

Grower retained seed may be of poor quality with reduced germination and vigour, as well as potentially being infected with seed-borne pathogens.

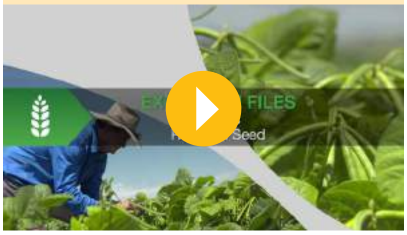
Seed quality may be adversely affected by several factors including:

- Early desiccation resulting in high levels of green immature seed and smaller seed size (affecting both germination and vigour).
- Cracking of the seed coat if the seed is exposed to several wetting and drying cycles. As the seed coat absorbs moisture it expands and then contracts as it dries. This weakens the coat increasing the risk of mechanical damage during harvesting and handling operations.
- Mechanical damage can result in reduced germination and vigour and increased susceptibility to fungal pathogens in the soil at sowing (exacerbated if establishment is delayed into cold wet soils).
- Delayed harvest due to wet weather can lead to increased (i) Native budworm damage; (ii) mould infection, and (iii) risk of disease.
- Harvesting at a moisture content more than 15% can lead to problems with moulds and fungal pathogens colonising on the seed coat during storage.
- Harvesting at a moisture content under 10% can result in mechanical damage to the seed coat and/or seed splitting, which is compounded each time the seed is handled.
- Poor (temporary) storage in the rush to get harvest done in wet weather can reduce viability of the seed resulting in poor germination and emergence.
- Seed-borne diseases all reduce the viability of the seed (germination and vigour). Crop establishment is reduced and any surviving infected seedlings act as an inoculum source to initiate disease infection within the new crop. [9]

NOTE: Do not use grain for seed of pulse crops harvested from a paddock that was desiccated with glyphosate. Germination, normal seedling count and vigour are affected by its use. Read the glyphosate label.

VIDEOS

WATCH: GCTV16: Extension Files – Retained Pulse Seed.



2.3.1 Seed size

The larger the seed, the larger the endosperm and starch reserves. Although seed size does not alter germination, larger seeds emerge earlier and faster than medium and small seeds. This is because larger seeds germinate more rapidly and their roots are longer than those of smaller seeds. With adequate moisture, medium-sized seeds will emerge in 5 or 6 days. Seed size is usually measured by weighing 100 seeds. The result is known as the 100-seed weight.

The 100-seed weight varies among varieties and from season to season. Therefore, sowing rates should be altered according to seed weight to achieve the desired plant population. Narrow-leafed lupin has a 100-seed weight of about 13 g, whereas albus lupin has a 100-seed weight of about 35 g.

Seed grading is a good way to separate good-quality seed of uniform size from small or damaged seeds and other impurities such as weed seeds. Grading is important when sowing into soils with marginal moisture or when sowing depth is uneven. Seed size and vigour are particularly important following drought years, when there is more small seed. Not only does seed size affect seedling vigour, it can also affect sowing rate. Sowing small lupin seeds at common sowing rates can result

8 L Jenkins, K Moore, G Cumming. Pulse Australia. Chickpea: High Quality seed. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/high-quality-seed

9 L Jenkins, K Moore, G Cumming. Pulse Australia. Chickpea: High Quality seed. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/high-quality-seed

in the establishment of very high plant populations per square metre. High plant populations use more soil moisture during vegetative growth, leaving less for grain filling, resulting in small seed and low yields at harvest. It is important to determine the 100-seed weight to determine appropriate sowing rates. [10]

It is recommended that both the germination test and seed size test be done on several lots of seed (i.e. at least twice) to get a more accurate assessment of the sample.

2.3.2 Seed germination and vigour

Always do a germination test on seed and adjust the sowing rate accordingly. Sowing quality seed is critical to achieving adequate plant density and high yields. In trials, yields increased by 20% when using high germination seed (more than 80%) compared with low-germination seed (50%, Photo 3), even when the seed rate was doubled to compensate.

Photo 3: *Deformed seedlings taken from a germination test.*

Source: DAFWA

10 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Headers easily damage seed, as does excessive handling during harvesting, grading and sowing. Rotary headers cause less damage.

Test germination in a laboratory or at home.

Calculating germination percentage

To calculate the germination percentage of a seed lot.

1. Using a graded seed lot, count out 100 seeds from each lot to be planted, including the damaged seeds.
2. Use a flat tray about 30 cm square and 5 cm deep (a nursery seedling raising tray is ideal). Place a single sheet of paper towel in the bottom to cover the drainage holes and fill with clean sand, potting mix or freely draining soil. (NOTE: If you don't have a tray the test can be done in any sort of self-draining container or in a cool part of the home garden.)
3. Take the 100 seeds (including the damaged ones) and sow 10 rows of 10 seeds (the rows make it easier to count the seedlings). Seeds should be sown at a normal seeding depth of 2 to 3 cm (Photo 4). (NOTE: Place the seeds on top of the sand or soil and push them in with a piece of dowel or a pencil and cover with more sand.)

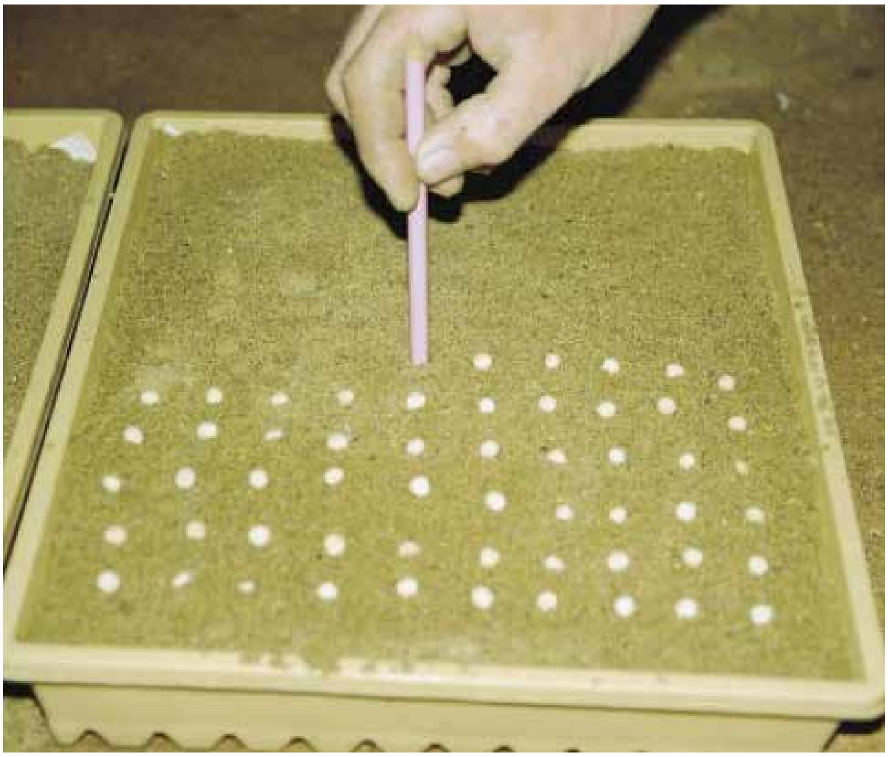


Photo 4: *Setting up a germination test in a seedling raising tray. Place 100 seeds on top of the sand and push them in 2–3 cm deep before covering.*

Photo: Di Holding, Source: NSW DPI

4. Water gently with a spray bottle. Keep moist (not wet). Overwatering will result in fungal growth on the seeds and may cause seed rot and affect normal germination.
5. Count the seedlings after 7 to 10 days, when the majority of seedlings are up. Do not wait until the late ones emerge. (These ones are damaged or have low vigour.)
6. Only normal seedlings should be counted - those with both cotyledons (seed leaves) present (Photo 5).

Photo 5: *Close up of newly emerged narrow-leaf lupin seedlings. The one circled is abnormal, missing a cotyledon. DO NOT count this one.*

Photo: Warwick Holding, Source: NSW DPI

7. Calculate your germination percentage (e.g. if you count 83 normal seedlings, then your germination percentage is 83%).
8. Repeat four times. [11]

Results of this test will inform sowing rates. For more information on sowing rates, see Section 3: Planting – section 3.6 Calculating sowing rate.

MORE INFORMATION

Germination testing and seed rate calculation

Diagnosing poor quality seed in narrow-leafed lupins

2.3.3 Bitterness in albus lupin

Albus lupins are sweet (low alkaloid) and ideal for human consumption. Cross-contamination with bitter lupins increases the bitterness of sweet lupin and therefore reduces their quality for human consumption. It is important that growers change completely to the new varieties to avoid crosspollination and contamination from older varieties, which could introduce bitterness. All seed should be tested prior to sowing for any bitter lupins.

To maintain the seed quality standards for the sweet (low seed alkaloid) albus lupin industry, growers should test all sowing seed for possible bitter (high alkaloid) contamination.

Since 2005, the sowing threshold for bitterness contamination has been 0%.
This aims to:

- keep the NSW albus lupin crop below the receival and export standard
- ensure that the level of bitter seed contamination does not increase in commercial seed crops
- reduce the chance of the newly released sweet albus lupin varieties becoming contaminated by bitter seed.

Even at a low level of contamination, the overall alkaloid level of the crop can exceed the threshold. There are two standards:

- The current Food Standard sets a threshold of 200 mg/kg of lupin alkaloids.

11 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

- Pulse Australia's Receival and Export Standards specify that bitter contaminants must be no more than 2 seeds per 200 g.

Any crops sown from potentially contaminated seed or lupini bean (a large seeded, bitter albus lupin) must be grown at least 2 km away from other albus crops.

Managing bitter seed contamination in sweet lupin

Avoid growing lupini bean (100% bitter, large seeded albus) in sweet albus production areas. These measures are to protect the most recently released 100% sweet albus varieties Luxor⍉A and Rosetta⍉A from bitter pollen contamination. Bitterness prevention in these new varieties is crucial to maintain the threshold standards set for albus for both human consumption and stockfeed use.

Only grow one albus lupin variety on the farm – discard old varieties – and keep a minimum one kilometre isolation from all other albus crops. Check with neighbours about their albus sowing intentions. If growing a small quantity of albus for seed increase, surround it with a narrow-leaf lupin crop – the agronomy is similar and the albus crop will be protected from pollen contamination by foraging honey bees. Test all sowing seed for bitterness every year, including new varieties. Do not buy any albus seed without a testing certificate showing that the seed is free from bitterness.

Bitterness seed testing for albus lupin is available through Futari Grain Technology Services, 34 Francis Street, Narrabri 2390 (phone 02 6792 4588). [12]

MORE INFORMATION

Testing albus lupins for bitter seeds

Lupini bean – a bitter contamination risk for sweet albus lupins

Calculating bitter seed percentage in albus lupin seed-lots

To identify bitter seeds in albus lupin seed lots:

1. Collect a random sample from a 1 kg seed lot either off the header or graded.
2. Using a ultraviolet lamp, screen the sample for the presence of fluorescing (pink) seeds.
3. Count seeds that are pink or purple.
4. Determine the bitter seed level (%).
5. Discuss options for the seed lot [13]

2.3.4 Seed storage

The aim of storage is to preserve the viability of the seed for future sowing and maintain its quality for market. Lupin seed stores well, being more resistant to weevil and insect attack than cereal grains. The conditions during storage can have a major impact on crop germination and establishment, so seed needs to be stored and handled correctly.

Pulses exposed to weathering before harvest deteriorate more quickly in storage. Most pulse seed should only be stored for 12 months, although longer storage periods are possible with high quality seed provided both grain moisture and temperature within the silo can be controlled. Rapid deterioration of grain quality occurs under conditions of high temperature/moisture and with poor seed quality including weathered, cracked and diseased seed.

Handling

Avoid excessive handling, as lupin seed is easily damaged. Damage can occur during harvest, grading and sowing. Handling after seed has dried below 15% moisture greatly increases cracking, which reduces germination.

One way to test for cracked or damaged seed is to soak the seed in 1 part ink and 9 parts methylated spirits. After being washed in clean methylated spirits, cracked

12 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

13 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

VIDEOS

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

MORE INFORMATION

Storing pulses

seeds retain the colour of the ink that has penetrated through the damaged seed coat. [14]

For more information, see Section 12: Harvest.

Temperature and moisture

At physiological maturity the lupin seed contains about 60% water. The seed then dries down to a moisture content of 15% by harvest time. Lupin seed stores best at a moisture content of between 13% and 14%. Seed stored at 13% to 14% moisture at 20°C has little quality loss. However, above 30°C, quality loss is considerable at these moisture levels. If high temperatures are unavoidable, storing seed at a lower moisture content (e.g. 10%) slows seed quality deterioration.

Reducing temperature in storage facilities (to below 30°C) is the easiest method of increasing seed longevity. Temperatures can be reduced in grain silos by painting the outside of the silo white (temperatures reduced by 4–5°C), and/or aerating silos with dry, ambient air. [15]

For more information, see Section 13: Storage.

2.3.5 Safe rates of fertiliser sown with the seed

Key points:

- Care must be taken to separate fertiliser and seed to prevent damage to emerging seedlings.
- Crops vary in their tolerance to fertiliser and fertilisers vary in toxicity. Lupins can be sensitive to fertiliser toxicity.
- Seeding systems with narrow seed spread, wide row spacing and no seed/fertiliser separation are more susceptible to toxicity.
- There is greater potential for damage when high fertiliser rates are used, especially in lighter soil types or cooler, drier seeding conditions.
- Seedbed utilisation is a method of quantifying safe fertiliser rates for different seeding systems

All pulses can be affected by fertiliser toxicity. Lupins are especially susceptible. Higher rates of phosphorus fertiliser can be toxic to lupin establishment and nodulation if drilled in direct contact with the seed at sowing. Drilling 10 kg/ha of phosphorus with the seed in 18 cm row spacings through 10 cm points rarely caused any problems. However, with the changes in sowing techniques to narrow sowing points, minimal soil disturbance, wider row spacings, and increased rates of fertiliser (all of which concentrate the fertiliser near the seed in the seeding furrow) the risk of toxicity is higher. Sowing into marginal moisture conditions can also increase this risk. This has concentrated much more fertiliser with the seed, and research suggests that this may be an issue with sensitive crops such as lupins. [16]

Lupins, and in particular albus or broadleaf lupins have been well known to be sensitive to large amounts of fertiliser next to the seed.

The effects are also increased in highly acidic soils, sandy soils and where moisture conditions at sowing are marginal. Drilling concentrated fertilisers to reduce the product rate per hectare does not reduce the risk. The use of starter nitrogen e.g. DAP, banded with the seed when sowing pulse crops has the potential to reduce establishment and nodulation if higher rates are used. On sands, up to 10 kg/ha of nitrogen in 18 cm row spacings can be safely used. On clay soils do not exceed 20 kg/ha of nitrogen in 18 cm row spacings. Deep banding of fertiliser is often preferred for lupins, or else broadcasting and incorporating, drilling pre-seeding

14 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

15 L Jenkins, K Moore, G Cumming. (2015). Australian Pulse Bulletin – Chickpea: High quality seed. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/high-quality-seed

16 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

or splitting fertiliser applications so that lower rates or no phosphorus is in contact with the seed. [17]

In a trial at Merriwagga, NSW in 2011, six varieties (three albus lupins and three narrow-leaf lupins) were sown and researchers found that the impact from fertiliser was greater at wider row spacings. Varieties were sown with either no fertiliser treatment or 60 kg/ha of Superfect. At 25 cm row spacing the impact of fertiliser had an equal effect on all varieties, so albus lupins and narrow-leaf lupins appeared to be as sensitive as each other to fertiliser damage at seeding. The impact of fertiliser on Rosetta⊕ was much larger than other varieties at wider row spacing, with damage felt even at 25 cm row spacing. This trial demonstrate that even low rates of fertiliser can affect the establishment of all varieties of lupins in some situations. Other trials have also shown lupins to be sensitive to fertiliser toxicity. [18]

The separation of seed from fertiliser is three-dimensional – along, across and down the furrow. The concept of seed bed utilisation (SBU) has been used to address this issue.

Factors to consider when selecting fertilisers and rates

There are several factors that contribute to the safe amount of fertiliser that can be placed with the seed.

Fertiliser type

All fertilisers are relatively concentrated chemical compounds that can affect delicate germinating seeds in a couple of ways.

Osmotic effect - In chemical terms fertilisers are salts and can affect the ability of the seedling to absorb water by osmosis. Too much fertiliser (salt) near the seed and desiccation or 'burn' can occur. However, fertilisers vary in salt index or burn potential depending on composition. As a general rule, most common nitrogen and potassium fertilisers have a higher salt index than phosphorus fertilisers.

Potential to release ammonia - Fertilisers that have the potential to release free ammonia can cause ammonia toxicity in seed. Consequently, in-furrow placement of ammonium phosphate and urea-containing fertilisers is usually not advisable. A solution of urea and ammonium nitrate (UAN) can be applied successfully in-furrow but there is a risk of ammonia damage where high rates are used, especially in situations when germinating seedlings are stressed.

Efficiency enhancers - Some strategies to enhance fertiliser efficiency, such as the use of polymer coatings or urease inhibitors will slow the rate of ammonia production and make these products less likely to cause crop damage.

Soil type and environment

Soil conditions that tend to concentrate salts or stress the germinating seed increase the potential for damage. So, the safe limit for in-furrow fertilisation is reduced with lighter soil texture (sands) and in drier soil conditions. It is also reduced when environmental conditions such as cool temperatures induce stress and/or slow germination. These can result in prolonged fertiliser-seed contact, increasing the likelihood of damage. Good rain immediately after sowing can reduce the potential for damage as salts are diluted and ammonia is dissolved, which reduces the concentrations around the seed.

Machinery configuration

The type of sowing point and seed banding boot used and the spacing between the drill rows both affect the concentration of fertiliser near seed and the likelihood of damage.

17 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/resources-and-publications/all-publications/publications/2008/03/2008-grains-legume-handbook

18 B Haskins (2011) Fertiliser toxicity in lupins. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/lupins/fertiliser-toxicity-in-lupins

Increasing seed bed utilisation (SBU) using seeding systems - When high SBU seeding systems were combined with high seed rate, the grain yield and crop/weed competition were both maximised. Practical options to achieve a high SBU include fitting paired row seeding boots to existing tillage systems, using greater soil disturbance ribbon sowing systems, or reducing row spacing. When tyne-based systems are used to achieve high SBU, stubble clumping is typically increased and uniformity of seeding depth decreased.

Row spacing - If the same fertiliser rate is used with different row spacings, then the amount distributed along each seeding row will increase as row spacing becomes wider. For example, the rate of fertiliser applied in a 30 cm row is basically double that of a 15 cm row. To avoid this increased fertiliser concentration in wide-row systems the safe rate of in-furrow fertiliser decreases as row spacing increases.

Table 6: *Approximate safe rates of P with canola seed if seedbed has good soil moisture (at or near field capacity). These values can be applied to lupin.*

	25 mm (I") seed spread[2]			50 mm (2") seed spread[2]		
Fertliliser type	Row spacing			Row spacing		
	180 mm (7")	229 mm (9")	305 mm (12")	180 mm (7")	229 mm (9")	305 mm (12")
		SBU[3]			SBU[3]	
	14%	11%	8%	29%	22%	17%
DAP (18:20:0)	8	6	5	17	13	10
MAP (10:22:0)	10	8	6	21	16	12
Triple Super (0:20:0)	27	21	15	55	42	33
Single Super (0:9:0)	15	12	9	31	24	18

2 Width of seed spread must be checked under field condition. Width of spread varies with air flow, soil type, moisture level, amount of stubble and other soil conditions.
3 SBU is the amount of the seedbed over which the seed/fertiliser has been spread. These models are yet to be confirmed and are a guide only – use half these rates in dry soil

Source: GRDC

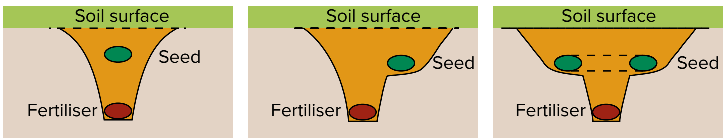
Seedbed utilisation - The concept of SBU has been used to help quantify this issue. SBU is simply the seed/fertiliser row width divided by the seed row spacing, that is, the proportion of row space occupied by the seeds. The wider the lateral seed spread, for a specific row spacing, the greater the SBU. As SBU increases, so does the safe rate of in-furrow fertilisation. The greater the lateral scatter of seed and fertiliser in the seed band or row (along, across and to depth) the more fertiliser that can be safely applied with the seed. The type of planting equipment and seed opener influences the closeness of seed-fertiliser contact (Table 4). For example, minimal lateral spread is achieved by many disc openers, with lateral spread generally increasing with share width. Double shoot/ribbon seeding openers, where seed is spread across a wider furrow, achieve the greatest lateral spread. When the lateral seed spread = share width = row spacing, a 100 per cent SBU is achievable.

Table 7: *Differences in seed bed utilization for a range of seeding points and boot combinations.*

Seeding Point	Common seed spread (mm)	%Seedbed utilization (SBU)		
		Row Spacing (mm)		
		150	225	300
125 mm share	65	43	29	22
65 mm share	46	31	20	15
Single side band opener	36	24	16	12
Spear point	25	17	11	8
Inverted T	25	17	11	8

Source: GRDC

Openers with split banding systems can separate the seed and fertiliser laterally and vertically (Figure 1 A, B and C). The greater the angle of the fertiliser boot to the seed boot the greater the vertical separation potential between the seed and fertiliser. The width of spread must be checked under field conditions. It may vary with air velocity, ground speed, seeding depth and soil conditions. Along with seeding system crop type, fertiliser and environmental conditions must still be considered. Seedbed moisture content is also an important factor, and damage is more likely with dry soils rather than moist soils. If the soils are dry or borderline, then rates should be altered. [19]



A. Single outlet with centre banding
Pros: Sub-seed soil disturbance, fertiliser separation banded at depth.
Cons: High draft and breakout force required compared with tillage at seeding depth, seed placement quality variable.

B. Single outlet with side banding
Pros: Sub-seed soil disturbance, fertiliser separation banded at depth, improved seed placement, good moisture transfer to seed.
Cons: High draft and breakout force required, potentially higher soil and residue disturbance.

C. Dual outlet paired row and ribbon sowing systems
Pros: Sub-seed soil disturbance, fertiliser separation, good seed placement except over centre section, higher seed-bed utilisation.
Cons: High draft and breakout force required, higher soil and residue disturbance influencing seeding depth uniformity.

Figure 1: *Three arrangements of split seed and fertiliser banding with tillage below the seeding point that illustrate the different types of seed and fertiliser separation achieved.*

Source: GRDC

MORE INFORMATION

Care with fertiliser and seed placement – GRDC Factsheet

19 GRDC (2011) Fertiliser Toxicity – Fact sheet: Care with fertiliser and seed placement. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/05/fertiliser-toxicity

Planting

Key messages

- Inoculate lupin with Group G inoculant, especially in paddocks where lupin have not been grown in the last five years.
- Lupin is sensitive to fungal disease. Applying seed treatments can reduce the incidence of disease, but be sure to check compatibility with inoculants used. Ensure to thoroughly read the labels of all products used.
- Lupins are often sown early as they need to take advantage of warmer temperatures for quicker seedling establishment, growth and nodulation. However, in some areas, sowing too early can result in excessive growth, lodging, and poor pod set.
- Lupin seed should be sown at a depth of between 1–5 cm.
- Lupin seed can be prone to damage during handling processes. Machinery may need to be modified to limit the amount of damage seed and to ensure successful seeding.
- Consider fertiliser rates at planting, particularly safe P and S rates

Growing a successful lupin crop is not technically difficult. New varieties and machinery are making lupins a more reliable and profitable cropping option.

The goals in establishing a lupin crop are:

- Effective pre-sowing weed control
- Optimum plant density (usually 35 or 45 plants per m^2)
- Effective incorporation of any pre-planting residual herbicides
- Surface stubble retention
- Placement of the seed at the correct depth
- Loosen soil below the seed for quick root growth
- Adequate fertiliser, placed separate from the seed to avoid toxicity
- Relatively loose soil above the seed

3.1 Inoculation

Key points:

- Lupin requires a specific rhizobium that is not found naturally in NSW soils. Lupin seed should be inoculated with Group G rhizobia before sowing. Serradella inoculant (Group S) is also compatible with lupins and can be used as a substitute if necessary.
- All lupins sown in a paddock for the first time should be inoculated with rhizobium. Take care with seed inoculation techniques, especially into paddocks where lupin has not previously been grown.

Nitrogen fixation by legumes does not happen as a matter of course. Compatible, effective rhizobia must be in the soil in which the legume is growing before nodulation and nitrogen fixation can occur. When a legume is grown for the first time in a particular soil, it is highly likely that compatible, effective rhizobia will not be present. In such circumstances, the rhizobia must be supplied in highly concentrated form as inoculants.

For example, trials in 2014 at Wagga Wagga found that lupin failed to nodulate without an inoculation treatment, indicating that at this site there were no compatible rhizobia in the soil. This reflects either no recent history of cultivation of these legume species at this site and/or poor rhizobia colonisation and survival. The untreated lupin plots became visibly yellow compared with treated plots, suggesting N in these plots was

MORE INFORMATION

Southern NSW research results

becoming limited. This result would be expected given the heavy demand of N from the crop at this time and the absence of nodulated plants in these plots. [1]

In comparison, similar trials at Yenda in the same year found that lupin effectively nodulated without inoculation, indicating that lupin rhizobia had colonised that site. [2]

Inoculation benefits:

- Inoculated legumes will fix 25 kg of nitrogen per tonne of legume shoot dry matter, on average
- Low soil nitrate levels, good nodulation and agronomic practices that promote high legume production all increase N inputs from N fixation
- Decomposing legume residues are a good source of slow-release nitrogen for a following crop
- Economic benefits of legumes in crop production systems can be substantial, both from N fixation and the disease-break effect. [3]

3.1.1 Nodulation and nitrogen fixation in lupin

The rhizobium will form active root nodules that will fix nitrogen. Lupin forms symbiotic relationships with *Bradyrhizobium lupini* bacteria to fix nitrogen. This symbiosis is considered very robust in terms of edaphic and climatic influences and is probably part of the reason why lupins often thrive in relatively infertile soils. The symbiosis is very tolerant of low soil pH but can become limiting at pH greater than 8, particularly in *L. angustifolius*.

The *Bradyrhizobium* bacteria penetrate the roots, causing an infection that becomes a nodule. The bacteria produce an enzyme (nitrogenase) that converts atmospheric nitrogen to ammonium-nitrogen. Nitrogenase requires a low-oxygen environment within the nodule to function. The level of oxygen in the nodule is controlled by leghaemoglobin. When the nodule is functioning, the leghaemoglobin gives the nodules their pink or red colour inside (Photo 1). A green or brown colour indicates that no nitrogen fixation is occurring.

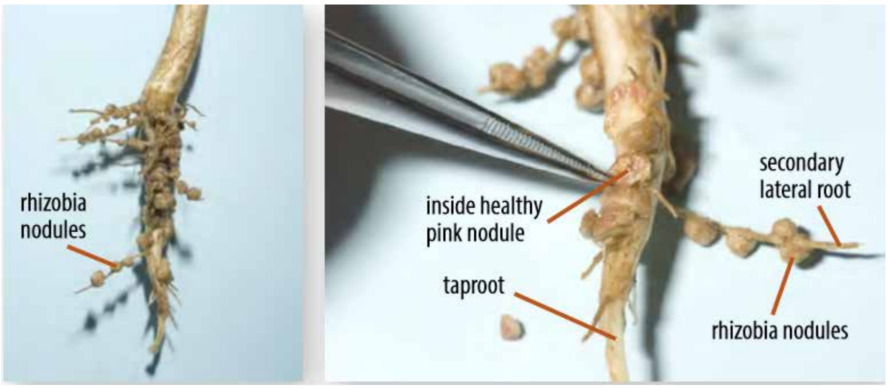


Photo 1: *Root system of lupin plant (left), showing nodules (right). The functioning nodules are a healthy pink/red inside. Photos: Lowan Turton,*

Source: NSW DPI

Albus lupin is able to produce a greater number of nodules of a greater size than narrow-leaf lupin due to its greater leaf size and amount of foliage. [4]

In lupin, the process of nodule initiation, infection, and development of a functioning nodule is different from that in other legumes. In other legume species, nodules

1 E Armstrong, G O'Connor, L Gaynor (2015) Nodulation studies with pulses on acidic red-brown soils - Wagga Wagga 2014. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/southern-nsw-research-results

2 E Armstrong, G O'Connor, L Gaynor (2015) Nodulation studies with pulses on acidic red-sandy soils - Yenda 2014. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/southern-nsw-research-results

3 GRDC (2013) Inoculating legumes: the back pocket guide. http://www.agwine.adelaide.edu.au/research/farming/legumes-nitrogen/legume-inoculation/inoclegubackpocketguide.pdf

4 J Carter. Nodulation assessment kit. Agriculture Victoria Institute for dryland agriculture. http://www.agwine.adelaide.edu.au/research/farming/legumes-nitrogen/legume-inoculation/nodulation_assessment_guide_jcarter_agvic.pdf

form after the rhizobia enter the plant root through a deformed root hair, forming an infection thread.

In lupin, the *Bradyrhizobium* bacteria penetrate the cells at the junction between the root hair base and an adjacent epidermal cell. There are no obvious signs of infection. The newly infected cells divide repeatedly 5 or 6 days after inoculation to form the central infected zone of the young nodule.

Nitrogen fixation does not start until 4 or 5 weeks after germination. Nitrogen does not accumulate in the shoots for a further 2 weeks. At this time all main-stem leaves have been initiated and five or six leaves are fully emerged. Nitrogen fixation stops with the onset of pod filling.

If phosphorus supplies are low, nodules grow mainly on the lateral roots in or near the proteoid root clusters of albus lupin. Mild phosphorus deficiency will result in an increased number of nodules, but the nodules will generally be smaller. [5]

Quantities of nitrogen fixed have been estimated using different methodologies and range from 20 – 400 kg N ha-1. The net nitrogen input (total fixed – removed in harvested grain) from *L. angustifolius* in Western Australia is believed to range from 32 – 96 kg N ha-1. [6]

The rhizobium can persist in the soil for up to five years once established, but its survival is reduced with increasing soil acidity or prolonged periods of low rainfall or drought. On acid soils (pH below 6.5) once a well nodulated lupin crop has been grown in the paddock, a lupin crop will not need to be inoculated for the next five years. If more than five years has passed, seed should be inoculated. On neutral and alkaline soils (pH above 6.5), the rhizobium do not survive in the soil for long, and seed must be inoculated every time a lupin crop is grown. [7]

IN FOCUS

N fixation by lupin may be large but it's economic value is small

Key points:

- Lupins fix large amounts of atmospheric N. However, much of this N is removed in the harvested grain. Thus, there is a smaller residual benefit to the following crop.
- This fixed N should not be considered 'free', with an opportunity cost that needs to be considered.
- The benefit of the residual N depends strongly on the use of fertiliser N. As more N is applied to the cereal crop the value of fixed N decreases.
- The economic decision to grow a lupin crop or not should be based around the commodity return from that lupin crop compared with other alternatives, with the residual fixed N being a 'bonus'.

A study in 2015 aimed to critically evaluate the economic value of fixed N in a lupin-wheat rotation compared to a continuous wheat-wheat rotation. The focus was on the economic value of fixed N and any opportunity cost from the commodity returns and did not account for other residual benefits from including a lupin crop as this would depend strongly on weed/disease pressures. Results indicated that under most economic scenarios the wheat-wheat rotation was more profitable than the lupin-wheat rotation.

5 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

6 http://www.lupins.org/explore/

7 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

Under most economic scenarios the wheat-wheat rotation was more profitable than the lupin-wheat rotation. This was because of the opportunity cost for growing lupin due to the low price of lupin grain. As the lupin price was increased the profitability of that rotation increased markedly relative to a wheat-wheat rotation. The other rotational benefits to wheat from including a lupin crop, such as a break in weed/disease cycles, have not been considered in this analysis. However, we can calculate what these would need to be. For example, the profitability difference between the two rotations with a low soil N, 100 kg N/ha fertiliser N applied a fertiliser price of $1.00/kg and a lupin price of $300/t was $343 in favour of wheat-wheat. At a wheat price of $300/t the additional yield in the second wheat crop, due to the weed/disease break, would need to be 1.1 t/ha. The difference in yield of wheat crop following lupins in WA is on average 0.6 t/ha greater than following wheat. However, this is an average result and there may be situations where the yield response following lupins is much higher (e.g. high weed or disease pressure).

The year-to-year variability in profit difference was also explored and largely followed the average values. The higher the mean value of profit difference the more likely the profit was positive. By far the most important determinant of the profitability difference was the rate of fertiliser N applied to the wheat crops. When no fertiliser N was applied to wheat the lupin-wheat rotation was more profitable in approximately 80% of years. However, when fertiliser N was applied the lupin-wheat rotation was less profitable in at least 80% of years. Commodity price, fertiliser N price and soil N level play decreasingly important roles in determining the difference in profitability (data not shown) when fertiliser N is applied to wheat.

Conclusion

The study neither advocated for or against including lupins in crop rotations. If they are profitable (based on yield and commodity price) compared with other alternative crops and provide substantial weed and disease breaks in rotation farmers should continue to include lupins in their rotations. The residual N benefit from Lupins is a minor part of the benefit of Lupin crops. Fertiliser N prices will need to increase substantially before fixed N will become an important part of the economic return from lupins. [8]

MORE INFORMATION

[The N fixation by a lupin crop may be quite large but it's economic value is small]

3.1.2 Application

Pulses have historically been inoculated with rhizobia onto the seed. But now rhizobia can be purchased in a form suitable to be applied with water into the soil, or as granules that are sown with the seed from a separate box. For water injection, the inoculant is mixed with water and applied at low pressure through tubes into each seed furrow. Using granules usually requires a third seed box as granules will shake out if mixed with seed and can lose viability if mixed with fertiliser.

Getting inoculation right:

- Use quality inoculants (the Green Tick logo is a trademark of AIRG* approval)
- Match the correct inoculant group to each legume
- Inoculants contain LIVE bacteria: make sure they are kept in moderate temperatures (less than 30°C, not frozen) away from sunlight and chemicals
- Sow freshly inoculated seed as soon as possible and definitely within 24 hours of inoculation

8 A Fletcher, R Lawes (2015) The N fixation by a lupin crop may be quite large but it's economic value is small. CSIRO Agriculture. http://www.giwa.org.au/pdfs/CR_2015/Fletcher_Andrew_The_N_fixation_by_a_lupin_crop_m(...)uite_large_but_its_economic_value_is_small_FINAL.pdf

- Use clean potable water for dilution when using liquids or slurries, and make sure holding tanks are free from chemical and fertiliser residues
- Many pesticides, mineral and organic fertilisers are toxic to rhizobia and should never be mixed with rhizobia
- Rhizobia can be compatible with seed pickles or dressings for a limited time prior to sowing. Always apply the seed dressing first and allow it to fully dry before applying the rhizobia as a second process
- Always use inoculants before their expiry date
- Reseal opened bags of peat inoculant and use them within two weeks of first opening the bag

Apply inoculant immediately before sowing. A number of new inoculant products are available for lupin such as freeze-dried and dry granular products – read the instructions and follow them carefully to avoid inoculation failure. [9]

All types of inoculants will result in a well nodulated crop in good conditions (Table 1).

Table 1: *Using different inoculant formulations.*

	Peat	Freeze-dried	Granular
Description	Finely ground sterilised peat containing a high density of rhizobia	Powder containing a very high density of rhizobia	Granules of peat or clay or a mixture; contain a lower number of rhizobia per gram
Storage	Winter legume inoculants – refrigerate at 4°C; summer legume inoculants – store in cool, dry place	Refrigerate at 4°C DO NOT FREEZE	Store in a cool and dry place away from direct sunlight
Common application	Mix with clean water to make a slurry, apply direct to seed. Can also be used in furrow.	Reconstitute with clean water and add protective compound. The liquid suspension is applied direct to seed or can be injected into the furrow	Granules are delivered in furrow at sowing. DO NOT allow granules to become moist during seeding as some products can cause blockages
Using additives	If used, ensure adhesive solutions are cooled before rhizobia are added. Generally NOT COMPATIBLE with mineral and organic fertilisers and pesticides; check manufacturer's guidelines	Generally NOT COMPATIBLE with mineral and organic fertilisers and pesticides; check manufacturer's guidelines	Check inoculant manufacturer's compatibility guidelines
Sowing	Best sown on day of coating into moist soil	Sow treated seed into moist soil within 5 hours of application	A third seeding box should be used to keep the granular formulation separate from fertilisers and pickled seed

Source: GRDC

9 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

When conditions are less than ideal, making the right choice becomes more critical (Table 2). Granules can vary and, depending on the product, may be dry or moist, uniform, variable, powdery, coarse or fine. The rhizobia bacteria need moisture to survive. When contained in the carrier; i.e. the peat material or the granule form, they will survive for up to 12 months when stored well. Read the expiry date before use.

However, once applied the survival rate is highly dependent on available soil moisture. This particularly applies to inoculum applied to the seed or to the soil as slurry. Dry soil conditions after sowing will kill off the rhizobia. Moisture will be needed within 2–3 days after sowing to maintain adequate numbers. If introduced rhizobia are essential for crop health, dry sowing should be avoided and caution should be used if sowing into a drying seed bed with a poor forecast for follow-up rain.

Granules by comparison are ideally suited to maintaining rhizobia numbers in dry soil for extended periods before rain arrives. The rhizobium is maintained within the granule which continues to protect it until the soil wets and the rhizobia can start multiplying. They are ideal to use if dry sowing is being considered. Additionally, they enable fungicides, which may be toxic to the rhizobia, to be applied the seed without causing a reduction in rhizobia numbers. [10]

Table 2: *Survival of rhizobia according to inoculant type and conditions at application.*

Inoculant type	Where inoculant should be applied	Survival in dry or drying soil*	Compatibility with seed applied fungicide	Time to sow after inoculation	Preparation or machinery requirements
Peat inoculums	Seed	Low	Some (check label)	24 hours	Pre-sowing/ Liquid applicator on seed
Freeze dried inoculums	Seed or in furrow (water inject)	Very low	No	Within hours	Pre-sowing
Granular forms	Seeding furrow or below seed	High	Yes	-	Separate seed box at sowing
In-furrow water injection	Seeding furrow or below seed	Very low	Yes	Within hours	Liquid applicator on seeder

*Survivial will depend on duration of dry conditions and soil pH

Source: Pulse Australia

When to inoculate

Pulses require the application of a rhizobia species that is specific to that pulse. If a pulse has not previously been grown in the paddock then the crop must be inoculated at sowing. Rhizobia will persist in the soil and, depending on a range of conditions, can inoculate a subsequent pulse.

If the paddock has previously grown the same pulse, the number of rhizobia remaining in the soil will be affected by the:

- time since the pulse was last grown
- health of the crop
- type of rhizobia
- soil pH and texture.

10 Pulse Australia (2015) Australian Pulse Bulletin: Pulse inoculation techniques. http://www.pulseaus.com.au/growing-pulses/publications/pulse-inoculation

VIDEOS

WATCH: GCTV13: Legumes – Sowing preparation.

Rhizobia types vary in their ability to persist in the soil until the host pulse crop is regrown. Lupin rhizobia are most resilient and survive very well in low pH (down to pH 5) sandy soils.

The cost of inoculation is low and worth the effort if there is any doubt about the viability of residual soil rhizobia.

A benefit of inoculating a crop where rhizobia already exist is that an improved strain will be introduced which could result in better persistence for future pulse crops. Research continues to find more robust and efficient rhizobia strains for all pulse species. The strain used today in any group will be more advanced than those introduced to a paddock in the past. [11]

Seed coating in practice

- Rates of application; i.e. volumes and weights of formulation, water and seed, are given on inoculant packets
- Peat formulation is made into a slurry using clean potable water in a clean drum and mixing well
- NOTE: Avoid fertiliser and pesticide residues and saline water
- Always grade seed first to remove pod debris and fine grain dust, which can block seeders
- Freshly prepared slurry is pumped from the drum (or poured) into the path of grain legume seed going up a slow-moving flighted auger into a grain bin
- Freeze-dried inoculant can be applied in the same way as peat slurry, as per manufacturer's instructions
- Allow slurry-treated seed to dry before filling air-seeders to prevent 'bridging' in the tank. [12]

The proven method of slurry inoculating the seed through an auger just prior to sowing still appears to be the cheapest and most reliable method (Photo 2). Alternative delivery methods using clay-based granules or water injection through micro-tubes are equally effective but considerably more expensive. These latter methods are best used when using sowing fungicide-dressed seed, to separate the rhizobia from the chemical.

11 Pulse Australia (2015) Australian Pulse Bulletin: Pulse inoculation techniques. http://www.pulseaus.com.au/growing-pulses/publications/pulse-inoculation

12 GRDC (2013) Inoculating legumes: the back pocket guide. http://www.agwine.adelaide.edu.au/research/farming/legumes-nitrogen/legume-inoculation/inoclegubackpocketguide.pdf

Photo 2: *Inoculating lupin seed through an auger. Don't forget to calibrate the amount of water required (too much will lead to sticky seeds).*

Source: GRDC

Storing inoculant

Storing inoculant One of the main factors affecting the quality of legume inoculants is storage temperature. Legume inoculants contain live rhizobia. It is important to make sure they are kept in moderate temperatures (less than 30 °C and not frozen) away from sunlight and chemicals. Inoculant quality at the point of sale at the point of sale has been monitored. Inoculants were purchased from retail outlets covering the grain cropping areas across Australia and the number of rhizobia in each packet or container counted. Temperatures and conditions of storage were recorded. Generally, rhizobial numbers in the inoculants remain high because the product at the point of manufacture had been prepared in a suitable carrier that prolongs rhizobial survival. However, numbers for the common legume host groups decline in rhizobial number when stored at ambient to high temperature compared to those stored at less than 10 °C (refrigerated). For the groups E, F, G, N and C there is a reduction of 22% or more in rhizobial numbers when the products are not refrigerated (Table 3). [13]

Table 3: *Effect of retail storage temperature on rhizobial survival in peat inoculants.*

Legume	Inoculant group	Million rhizobia/g peat		
		Refrigerated <10°C	Ambient >20°C	Difference (%)
Lupin	G	1,661	1,226	-26

Source: NSW DPI

13 E Hartley, G Gemell, J Hartley (2015) Use of quality legume inoculants to get the most from nitrogen fixation. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/southern-nsw-research-results

3.1.3 Compatibility with other major factors

Pesticides and fungicides

Rhizobia are living organisms. As a general rule, pesticides and fungicides are toxic to rhizobia.

Almost all pulses require a fungicide applied to the seed to provide protection during early growth against foliar diseases. Occasionally an insecticide may also be needed.

Peat inoculants are also applied to the seed, bringing together two largely incompatible products. Mixing inoculum with a pesticide for seed treatment is possible with some products. Read the inoculum label to check for compatibility. However, the seed must be sown within several hours into moist soil to avoid reducing rhizobia viability.

Applying the fungicide to the seed prior to the inoculum is a safer method to reduce the risk of rhizobia death. The fungicide can be applied at any time leading up to sowing. The inoculum is then applied immediately before sowing into moist soil. If in doubt, do not mix the inoculant and any pesticide.

Granular inoculants remove this risk because the rhizobia and the pesticide are not in contact. If you need to use a potentially toxic seed pesticide treatment, granular inoculant may be worth considering.

Caution should be used when treating pulse seed with a fungicide. Some insecticide and seed treatments can also cause problems. Check the inoculant and chemical labels for compatibility of the inoculant and fungicide or insecticide seed treatments.

Always read the inoculant label or contact the manufacturer for up-to-date information on compatibility. [14]

Effect of fungicidal seed dressings on inoculum survival

While fungicide seed dressings reduce the longevity of the N-fixing bacteria applied to the seed, the effect can be minimised by keeping the contact period to as short as possible (Table 4).

Inoculate fungicide-treated seed as close as possible to the time of sowing.

Re-inoculate if not planted within 12 hours of treatment.

Table 4: *Effects of fungicide seed dressings on plant growth and nodulation in chickpeas.*

Treatment	Fresh weight (g)			Height (cm)	Nodulation score
	Shoot	Root	Total		
Nil	106	142	248	47	1.0
Inoculum only	130	244	374	57	4.5
Inoculum + Thiram	103	182	285	55	1.8
Inoculum then Thiram	119	208	327	58	3.2
Thiram then inoculum	117	212	329	55	3.8
Inoculum + Apron	106	173	279	54	1.8
Inoculum then Arpon	114	207	321	59	3.3
Apron then inoculum	113	206	319	55	3.6
l.s.d (P = 0.05)	19	33	31	9	0.6

Source: Trevor Bretag, formerly DPI Victoria

VIDEOS

WATCH: GCTV13: Legumes – Inoculant compatibility.

14 Pulse Australia. Pulse inoculation techniques. http://www.pulseaus.com.au/growing-pulses/publications/pulse-inoculation

MORE INFORMATION

Pulse inoculation techniques

Inoculating legumes: a practical guide (GRDC)

Inoculating legumes: the back pocket guide (GRDC)

Rhizobia inoculants fact sheet (GRDC)

Maximising the nitrogen (N) benefits of rhizobial inoculation

Trace elements

Rhizobia can be compatible with a few specific trace element formulations, but many are not compatible with rhizobial survival. Mixing inoculants with trace elements should only occur if the trace element formulation being used has been laboratory-tested against the rhizobial type being used.
Note the differences between inoculant types for a given trace element product, as well as differences between trace element products with a given inoculant.

The following mixtures are NOT compatible with peat, liquid and freeze-dried inoculants:

- chemicals containing high levels of zinc, copper or mercury;
- fertilisers and seed dressings containing sodium molybdate, zinc and manganese.

3.1.4 Assessing nodulation

Do not assume that by applying rhizobia to the crop that the job is over. It's important to see how effective the inoculum has been and what state of health the nodules are in. By checking the degree of nodulation, you can assess the type of inoculum product you have used and the application technique employed to get the rhizobia where it needs to be; in the roots of the growing pulse. [15]

Nodules will have developed and be easily located from 8 to 10 weeks after sowing. Nodule assessment should occur any time from this point through to the end of flowering. For practical reasons, crops are more easily traversed when plants are young, and it is best to dig when the soil is moist and friable, allowing it to be easily crumbled from the roots.

To assess the effectiveness of crop nodulation and the health of nodules:

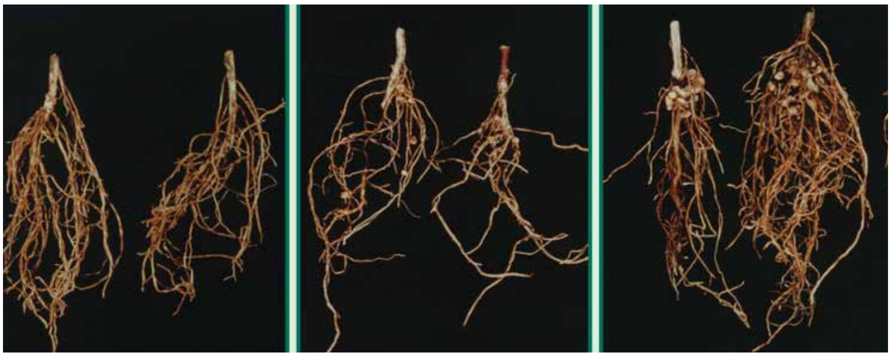
1. Carefully dig up 10 plants from each of several locations in the paddock and soak in bucket of water.
2. Locate nodules. A well-nodulated plant has nodules on the crown (where the root meets the shoot) and on the tap root and lateral roots.
3. Note their distribution, on the primary root and lateral roots.
4. In lupin, the crown region (top of root system) should be covered with nodules (Photo 3).
5. Slice open a nodule. Check the colour inside the nodule. Is it pink/red or green or brown? Pink-coloured tissue indicates active N fixation.
6. Score 10 plants for nodulation and record (Photo 4).
7. Look at root health and structure. [16]

15 Pulse Australia. (2015). Australian Pulse Bulletin: Pulse inoculation techniques. http://pulseaus.com.au/growing-pulses/publications/pulse-inoculation

16 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 3: *Well-nodulated lupin, showing pinkish colouring (left). In lupins, good nodulation often occurs mainly on the tap root (right).*

Photo: R. Ballard. Source: NSW DPI



Score 0: taproot, absent; lateral, absent/few.

Score 1: taproot, few/ medium; lateral, absent.

Score 2: taproot, medium; lateral, absent/low.

Score 3: tap root, medium/ high; lateral, low.

Score 4: taproot, high; lateral, medium.

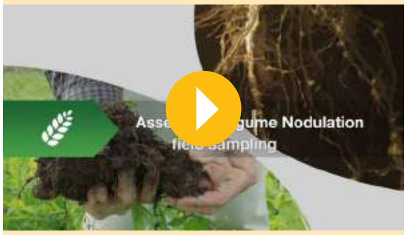
Score 5: taproot, high; lateral, medium.

Photo 4: *Photo guide to assessing legumes nodulation.*

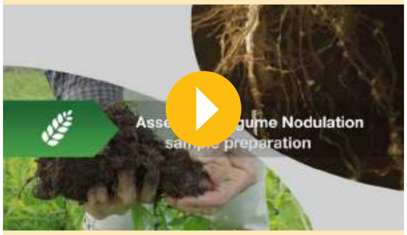
Photos: A Gibson.

VIDEOS

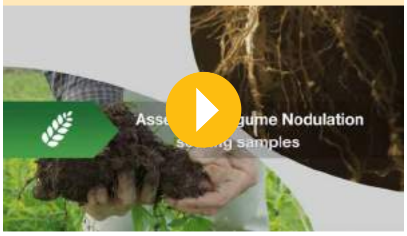
WATCH: GCTV17: Legume nodulation — field sampling.



WATCH: GCTV17: Legume nodulation — sample preparation.



WATCH: GCTV17: Legume nodulation — sample scoring.



Troubleshooting nodulation failure

Nitrogen deficiency from nodule dysfunction can be caused by lack of Rhizobia, soil conditions, herbicide toxicity, or molybdenum or cobalt deficiency. Indications of poor nodulation are yellowing young leaves, yellow and/or stunted patches of plants, and lack of nodules on root systems (Photo 5).

Photo 5: *Scattered nodulated narrow-leafed lupin plants.*

Source: DAFWA

What to look for in the paddock

- Smaller paler plants, with severity often varying with soil type.
- Plants frequently recover in spring.

What to look for in the plant

- Smaller paler plants with thinner stems and fewer laterals.
- Nodules are reduced or absent.
- If nodules are present they are small, and when split have pale or white, rather than pink interiors.
- Plants frequently recover in warmer weather as plant growth increases and nodules form on lateral roots. [17]

If there is poor nodulation, check the inoculation strategy to ensure best management practices are followed. If both nodulation and plant performance are poor, reasons

17 DAFWA (2015) Diagnosing nodule dysfunction in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-nodule-dysfunction-narrow-leafed-lupins

for poor nodulation need to be identified. Poor nodulation can cause 10–50% yield loss in pulse crops, as well as the lower potential nitrogen benefits to following crops. While a visual assessment will not indicate the actual level of nitrogen being fixed (only sophisticated scientific methods can do that) looking at the roots to determine if there has been a nodulation delay or failure is worthwhile.

Nodulation failure is difficult to remedy, except by adding inorganic nitrogen, which can be costly. Other possible remedies (if done immediately) include:

- In flood or sprinkler-irrigated fields, add slurry or liquid inoculant to the irrigation water
- Over-sow a granular inoculant close to the original sowing furrow. [18]

3.2 Seed treatment

It is recommended that, whenever possible, seed should be obtained from a source where the crop was free from disease. Seed treatments are a cheap and effective method for suppressing some diseases (Table 5). Fungicide seed treatments (e.g. Thirams) do not combine well with rhizobium bacteria used for inoculation. Read labels for compatibilities. Seed should be treated with fungicide and then, in a separate operation, inoculated with rhizobium. [19]

Keep up to date with NSW DPI recommendations following the anthracnose outbreak.

Fungicide seed dressing of P-PICKEL T® had no visible detrimental effect on nodulation in lupin at trials in Wagga Wagga in 2014. [20]

Table 5: *Lupin seed dressing – 2017.*

Example seed treatment, trade name and manufacturer	Active ingredient of fungicide or insecticide	Rate to apply to each 100 kg of seed	Approximate costs to treat 100 kg ($)#	Range of pack sizes (kg or L)	Lupin
Powders					
Thiragranz* - Crop Care	thiram (800 g/kg)	150 g chickpea 125–150 g lupin	2.15 1.80–2.15	20 kg	Seed-borne anthracnose
Flowable liquids					
Danadim® - Cheminova Dimethoate400 - Adama	Dimethoate (400 g/L)	150 mL (field pea) 150 mL (lupin) 330 mL (canola)	1.50 1.50 3.35	10–110 L 5–200 L	Redlegged earth mite, lucerne flea
Gaucho®600 – Bayer Crop Science	Imidadoprid (600 g/L)	300 mL (lupin) 400 mL (canola) 120 mL (faba bean) 60 mL (field pea)	12.55 16.75 5.00 2.50	1–200 L	Redlegged earth mite, blue oat mite
Emerge™Flowable Seed Treatment -Syngenta	Imidadoprid (600 g/L)	300 mL (lupin) 400 mL (canola)	11.10 14.80	1 & 10 L	Redlegged earth mite, blue oat mite
Cosmos® - Agriphar Crop Solutions	Fipronil (500 g/L)	400 mL	111.40	5–1000 L	-
Cruiser® Opti – Syngenta	Thiamethoxam (240 g/L + lambda-cyhalothrin (37.5 g/L)	500–1000 mL	69.00–138.05	-	-

18 GRDC (2013) Inoculating legumes: the back pocket guide. http://www.agwine.adelaide.edu.au/research/farming/legumes-nitrogen/legume-inoculation/inoclegubackpocketguide.pdf

19 I Pritchard (2015) Lupin essentials – growing a successful lupin crop. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4

20 E Armstrong, G O'Connor, L Gaynor (2015) Nodulation studies with pulses on acidic red-brown soils - Wagga Wagga 2014. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/southern-nsw-research-results

Example seed treatment, trade name and manufacturer	Active ingredient of fungicide or insecticide	Rate to apply to each 100 kg of seed	Approximate costs to treat 100 kg ($)#	Range of pack sizes (kg or L)	Lupin
		1000 mL	138.05		
Jockey® Stayer® - Bayer CropScience	Fluquinconazole (167 g/L)	2 L	123.50	5–1000 L	-
Apron®XL350ES – Syngenta	metalaxyl-M (350 g/L)	75 mL	32.95	1–1000 L	-
Maxim®XL – Syngenta	Fluidioxonil (25 g/L) + metalaxyl-M (10 g/L)	200–400 mL	68.35–136.75	1–1000 L	-
P-Pickel T® - Crop Care	Thiram (360 g/L) + thiabendazole (200 g/L)	200 mL	7.85	10 & 200 L	-
Poncho® Plus – Bayer Crop Science	Clothianidin (360 g/L) + imidacloprid (240 g/L)	500 mL	139.20	5–1000 L	-
Thiram 600 Flowable Fungicide – Crop Care	thiram (600 g/L)	200 mL (chickpea) 170–200 mL (lupin)	2.85 2.45–2.85	10–200 L	Seed-borne anthracnose
Rovral® Liquid Seed Dressing – FMC	Iprodione (250 g/L)	100–500 mL	2.25–11.20	5–1000 L	Brown leaf spot
Sumisclex® Broadacre – Sumitomo	Procymidone (500 g/L)	100 or 200 mL	5.25 or 10.50	20 L	Brown leaf spot
In furrow treatments		**Rate per hectare**	**Cost per hectare ($)**		
Intake® Hiload Gold – Crop Care	Flutriafol (500 g/L)	200 mL	4.50	5–1000 L	

* Wettable granule formulation.
# Prices quoted are GST Inclusive at 15 January 2017 and approximate only. Prices will vary depending on pack size purchased, seed treatment services; i.e. imidacloprid + fluquinconazole or Poncho Plus + fluquinconazole, and special marketing arrangements.

Source: NSW DPI

3.2.1 Application

It is important for seed treatments to be evenly distributed on seed to ensure each seed gets an effective dose. This is enhanced for flowable seed treatments by dilution with water (refer to the label). Secondary mixing of treated seed through an auger assists to obtain even seed coverage. Correct calibration of the applicator and a consistent seed flow are critical for the recommended rate of seed treatment to be applied.

3.3 Nutrition at sowing

Key points:

- Drill phosphate at seeding. Banding of phosphate below the seed can increase yields on some soils, particularly those with high phosphorous retention.
- If needed apply potassium within four weeks of sowing.
- On potentially manganese-deficient soils (mainly light sands), manganese can be applied as manganese super deep banded under the seed; alternatively, it can be applied as a spray when first pods are 2.5 cm. [21]
- Starter fertilisers blended with a sulfur component are recommended in areas where soil sulfur is very low. [22]

21 I Pritchard (2015) Lupin essentials. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C2

22 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

- Inoculated seed and acidic fertilisers should not be sown down the same tube. The acidity of some fertilisers will kill large numbers or rhizobia. Neutralised and alkaline fertilisers can be used. [23]

3.3.1 Phosphorus

In all lupin species, phosphorus deficiency is seen as poor growth of roots and shoots. In narrow-leafed lupin, phosphorus deficiency is seen when the leaves die back from the tips, followed by plant drooping. In albus lupin the leaves become a mottled yellow before dying from the tips.

Soil phosphorus levels influence the rate of nodule growth. The higher the phosphorus level the greater the nodule growth. Phosphorus is an essential part of the enzymes that fix light energy during photosynthesis and is needed for cell division and expansion. Nitrogen fixation has a high phosphorus demand. Many NSW soils are phosphorus deficient. Compared with nitrogen, phosphorus is relatively immobile in the soil. Lupin is very effective at obtaining phosphorus from the soil, and deficiency is rare in albus lupin.

Placing fertiliser with the seed at sowing at levels greater than 15 to 20 kg P/ha can reduce crop emergence. Damage will be greater in drier soils. Banding phosphorus below the seed can reduce damage without reducing availability to the plant. Generally, banding fertiliser below the seed gives higher yields than placing it with the seed. Research on red-brown earths in southern NSW showed a slight increase in yield when the fertiliser was banded below the seed (Figure 1). [24]

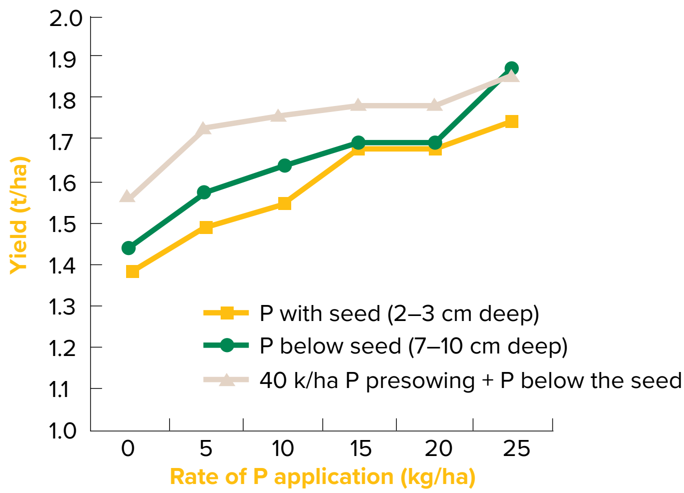


Figure 1: *Yield response of lupin to fertiliser placed with the seed, below the seed, or below the seed with 40 kg/ha surface-incorporated before sowing. Data are averaged across two sites and 2 years.*

Source: Modified from Scott et al. (2003) in NSW DPI

3.3.2 Nitrogen

Lupin is a legume and can fix its own nitrogen. Fixed nitrogen is available to the plant 5 or 6 weeks after emergence. On infertile soils, nitrogen deficiency can develop early in crop development, before enough nitrogen has been fixed. In some cases, using starter nitrogen can improve early plant vigour.

23 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

24 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

MORE INFORMATION

Targeted nutrition at sowing Factsheet

Nitrogen fertilisers in small amounts (5 to 15 kg N/ ha) are not harmful to nodulation and can be beneficial by pushing out the early root growth to establish a stronger plant. M.A.P. or D.A.P. fertilisers can be used but contain P so need to be aware of P toxicity if banded with seed. Excessive amounts of nitrogen will restrict nodulation and reduce nitrogen fixation. [25]

3.3.3 Molybdenum

Molybdenum is a trace element that is essential for the rhizobia to fix nitrogen and as part of the enzyme that converts nitrate to nitrite in cells. Molybdenum and cobalt (which is also required for nodulation) should be applied as needed. Lupin is grown in acid soils, which are often low in molybdenum. Molybdenum is strongly retained by soils at low pH (below $pHCaCl_2$ 5.0) and is usually deficient only is these low pH soils. Deficiency can be counteracted by using seed with a known high level of molybdenum; raising the pH of the soil; coating the seed with molybdenum fertiliser; using a fertiliser containing molybdenum; or applying molybdenum with herbicide. Proteoid roots can also increase the availability of molybdenum in albus lupin. [26]

For more information on micronutrient requirements, see Section 5: Nutrition and fertiliser.

3.4 Time of sowing

Sowing time affects the timing of flowering and the length of the seed filling period. Sowing should be done early enough to allow a long seed-filling period before soil moisture and high temperatures become limiting, but late enough to reduce the risk of frost damage. Early sowing is also important to ensure adequate growth before winter, as the growth rate of lupin is very slow in winter. However, early sowing in high rainfall environments can produce large amounts of vegetative growth. This increases water use and the crop's susceptibility to spring moisture stress. In Australia, lupins are autumn sown, with terminal drought determining crop ripening. [27]

The sowing time recommendations for lupins are not based on the variety (Table 6). This is because there is a narrow range of maturities in commercial lupin varieties. [28] Lupins are reputed to have the greatest requirement of all the pulses for early sowing as they need to take advantage of warmer temperatures for quicker seedling establishment, growth and nodulation. However, in some areas, sowing too early can result in excessive growth, lodging, and poor pod set, particularly on fertile soils. Early sowing can also result in frosting in some areas. Late-sown lupins can be shorter and yield considerably less, especially on infertile soils. It has been estimated that a yield loss of 180 kg/ha is felt for each week lupin sowing is delayed. The risk of damage by wind erosion is greater in late sown lupins, especially if reduced tillage and stubble cover is not used. [29]

Table 6: *Suggested sowing times for narrow-leaf and albus lupin in the Northern region.*

	April				May			
Week	1	2	3	4	1	2	3	4
Low rainfall								
High rainfall								

Red = preferred sowing time
Orange = Later than recommended, yield reduction likely depending on spring condition
Source: NSW DPI

25 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

26 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

27 http://www.lupins.org/production/

28 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

29 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

3.4.1 Time of sowing trials, NSW, 2016

Two experiments were conducted in 2016, which aimed to compare growth, development and yield of 12 current commercial lupin varieties and advanced breeding lines at three times of sowing (28 April, 17 May and 2 June) at Wagga Wagga and two sowing times (4 May, 20 May) at Yenda.

Key findings at Wagga Wagga

- Given a very long and favourable season and 525 mm of GSR at this site, there was no significant main effect of sowing time from 28 April to 2 June.
- The albus varieties yielded significantly higher at 17 May (3.56 t/ha) than the earlier 28 April (3.2 t/ha) and later sowing 2 June (2.95 t/ha) sowing dates (Figure 2).

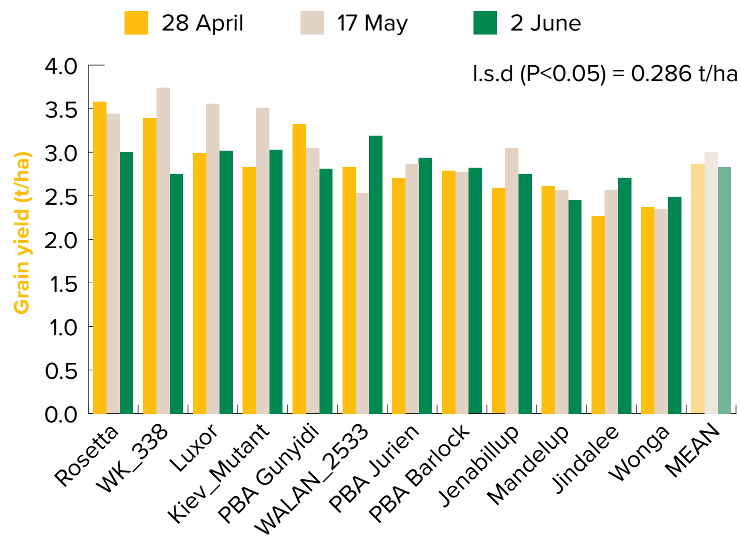


Figure 2: *Grain yield of 12 lupin varieties sown at three dates at Wagga Wagga in 2016 (column on left is earliest sowing date).*

Source: GRDC

Key findings at Yenda

- Averaged across species, angustifolius was 19% and 10% higher yielding than albus when sown on the 4th of May and when sown on the 20th of May, respectively (Figure 3).
- PBA Jurien⦇ and Mandelup⦇ were the only varieties to yield significantly higher 12.9% and 20.3%, when sown on the 4th of May and when sown on the 20th of May, respectively (Figure 3).
- There was no significant response to sowing time in any of the albus varieties tested.

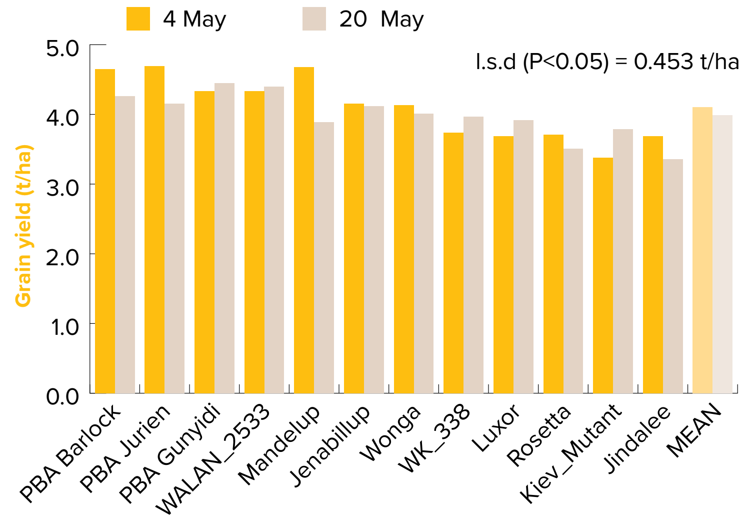


Figure 3: *Grain yield of 12 varieties sown at two dates at Yenda in 2016 (column on left is earliest sowing date).*

Source: GRDC

3.4.2 Frost risk

Strategies to minimise frost damage in pulses work in combinations of either: growing a more tolerant species; trying to avoid having peak flowering and early podding during the period of most risk; extended flowering to compensate for losses to frost; or ensuring that most grain is sufficiently filled to avoid damage when frost occurs. Targeting flowering and early podding to periods of least frost risk (lowest probability) is achieved through combinations of sowing date and variety choice based on flowering time and flowering duration. Local experience will indicate the best choices.

All current lupin varieties are susceptible to frost damage. Lupins are most vulnerable during the reproductive phase, which occurs once they initiate stem elongation. Frost damage risk can be reduced by not sowing varieties earlier than the recommended sowing window to avoid flowering in July to early August. For most lupin-growing areas in southern NSW, sowing before late April with early flowering varieties such as Mandelup⍉ increases the risk of frost damage. [30]

For more information on Frost risk and frost management, see Section 14: Environmental issues, section 14.1 Frost

3.4.3 Considerations when dry sowing

Dry sowing is a means of getting crops sown on time in seasons with a delayed break. Growers must sow on time if they want to get the best yield, so if the time comes for sowing and it hasn't rained, consider sowing dry.

Dry sowing lupin is an option, with grower experience showing it to be successful in establishing crops on time.

The biggest risk of failure when dry sowing pulse crops is the survival of rhizobia and subsequent nodulation. Dry sowing can be difficult on virgin lupin paddocks where inoculation will be required and rhizobia survival could be poor. New granular inoculants might help in this regard. [31] Narrow-leaf lupins sown into a paddock with

30 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

31 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

a history of lupins are the safest pulse crop to try. The risk of nodulation failure is greatly reduced where a background population of rhizobia is present in the soil.

Broadleaf weed control is the other key factor to consider when dry sowing.

Why dry sow?

The reason for dry sowing is to get more crop in on time. It lets growers:

- optimise all crop yields by sowing each one on time,
- sow more crop on time without the cost of increasing machinery size,
- spread labour requirements and operations,
- handle more trash while stubble is dry,
- warm soil conditions aid crop establishment.

Paddock selection

Normal paddock selection criteria apply for each pulse species. Look at soil pH, soil drainage and weed burden. The best results from dry sowing occur on freely draining, well structured soils but it is also successful on other soil types. Avoid hard setting or crusting soils. Stubble also helps retain soil moisture and reduces the risk of pulse diseases such as brown leaf spot in lupins.

Weed management

Knowledge of likely weed species in a paddock is essential, and the ability to control them under dry sowing conditions should be determined. Triazine herbicides are effective in dry sowing and stubble retention situations. They should be applied to moist soil post sowing /pre-emergent. Do not apply triazines to dry soil, as heavy rain will leach the herbicide reducing efficacy and risking crop damage.

Rhizobia survival

Survival of rhizobium is the biggest risk when dry sowing. Research suggests that survival under these conditions can be limited.

Ensure maximum survival of rhizobia on the seed during the sowing process:

- Use cool water to mix the inoculum slurry and clean containers (avoid those used for pesticides).
- Keep treated seed out of direct sunlight.
- Avoid treated seed contact with hot augers, grouper, seeding tynes.
- Plant at cooler times of the day avoid really hot conditions.
- Use a higher rate of inoculum to increase the number surviving on the seed.
- Avoid fungicide seed dressings as these may reduce survival. If seed dressing is essential to reduce disease risk, don't dry sow.
- Use molybdenum in districts where soils have low levels, to assist nodulation.

Seeding machinery

Major changes to seeding machinery for dry sowing are not required. You will need enough tyne break out pressure to penetrate the soil and maintain even seeding depth. Narrow seeding points with tungsten give better results and trash flow is often better when stubble is dry. Ensure that the sowing boot is set up so the seed is dropped at the bottom of the trench, but with some loose soil beneath it. Press wheels or cultipackers are the better covering devices. They pack soil over the seed providing good seed/soil contact and don't create dust problems like covering harrows.

Sowing—date, rate, depth and row spacing

Start dry sowing at the beginning of the normal sowing window. As a guide, sow no earlier than the third week of April for low rainfall zones, and the fourth week of April for high rainfall zones. Row spacing, seeding rate and seed depth should all be maintained as for normal sowing. Place seed at the deeper end of the recommended range to reduce the risk of partial germination on light rain, and to maximise rhizobium survival. Row spacing can be increased to handle heavy stubbles with minimal reduction in yield. [32]

3.5 Targeted plant population

Sowing rate affects plant establishment and is an important crop management decision. Sowing rate will vary depending on which pulse is being planted, the region, the rainfall, and the sowing time. With narrow leafed lupins there is less concern with plant population per se, since small lupin seeds can lack early vigour. Increased plant numbers can help to overcome the problem of using small seed with less vigour. [33]

Unlike cereals, lupin does not tiller, so it is important to establish an appropriate plant population. Plant population is determined by seeding rate and establishment percentage. The current recommendation for NSW ranges from 35–45 plants per m^2, depending on location and sowing time. For early sowing, a plant population of 35 plants per m^2 is best. In the higher rainfall zones or with later sowing, optimum yield comes from establishing at least 45 plants per m^2. [34]

There is no yield increase with higher plant populations. A plant density higher than 65 per m^2 reduces lateral branching and can cause problems at seed fill if there is not enough moisture. [35]

When sowing lupin crops try to achieve between 45 - 60 plants per m^2 or, 75 – 100 kg a hectare, or 35–45 plants per m^2 in southern NSW .

3.6 Calculating seed requirement

The correct plant density is an important factor in maximising yield of pulse crops. To obtain the targeted density it is necessary not only to have quality sowing seed but also be able to accurately calculate seeding rates. It is surprising the difference a slight variation in seed size or germination makes to the seeding rate required to achieve a target plant density. [36]

Sowing rates will vary depending on seed size and germination percentage. Albus lupin seed rates are much higher than narrow-leaf varieties due to their large seed size (Table 7). [37]

Table 7: *Lupin sowing rates (kg/ha) based on 100% germination and 80% establishment.*

Lupin type	100 seed weight (g)	Target plant density	
		35 plants/m^2	45 plant/m^2
Narrow-leaf lupin	13	56	73
Albus lupin	35	153	197

Source: NSW DPI

Calculating 100-seed weight

To determine the 100-seed weight of a seed lot:

32 D Carpenter (1999) Dry sowing. Pulse point. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/157117/pulse-point-06.pdf

33 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

34 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

35 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

36 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

37 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

1. Take a representative sample of your seed lot. If it is ungraded, weigh out 50 to 100 g and remove damaged and split seed that would normally be discarded by grading.
2. Count out 200 seeds from each seed lot to be planted.
3. Weigh 200 seeds on scales accurate to 0.1 g.
4. Divide the weight by 2 to calculate the 100-seed weight.
5. Repeat four times from your sample.

3.6.1 Calculating seeding rate

Calculate a seeding rate based on a target plant population:

1. Decide on a target plant density
2. Calculate the 100-seed weight (see above)
3. Calculate the germination percentage of the seed lot (see Section 2.3.2). Determine the establishment percentage. A realistic estimate of establishment is 80%. Take into account the likely field conditions (temperature, moisture, soil type, sowing depth, insects and disease).
4. Use the following formula to calculate seeding rate:

Seed rate (kg/ha) = (target plant density (plants/m^2) × 100-seed weight (g) × 1000) / (germination % × establishment %) [38]

3.7 Sowing depth

Sowing depth is the key to uniform, fast emergence and establishment. Despite the large seed size, shallow sowing results in better establishment. Under optimum moisture levels a depth of 1 cm will give the most even emergence. However, this depth is not ideal for root development or for emergence under variable moisture conditions. Root development is improved when the sowing depth is 2 cm. To allow good establishment and let the cotyledons emerge, sowing depth should not be more than 5 cm (Photo 6). If sowing is too deep (e.g. chasing moisture) the large cotyledons will be unable to emerge.

38 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 6: *Emerging albus lupin sown with disc seeder at an ideal depth of 2 to 4 cm.*

Photo: J Walker, NSW DPI

Albus lupin has a much larger seed than narrow-leaf types – if the soil moisture is marginal then albus seeds are at greater risk of not imbibing enough water, resulting in false germination. Deeper sowing into warmer soils (moisture seeking) can be a successful method to allow earlier sowing, but is risky, especially with larger-seeded albus. Low vigour seed and sowing late into soils with low temperatures results in poor establishment and often crop failure, especially in albus lupin. [39]

Direct drilling seed is a best practice, with hard setting heavier soils sown shallower and looser sandy soils. [40]

3.7.1 Sowing depth, disease and herbicide interaction

Sowing depth of lupins can influence the incidence of root diseases. Shallow sowing will increase the damage caused by pleiochaeta root rot, particularly if the soil has been cultivated beforehand or lupins have been intensely grown in the rotation.

39 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

40 Agriculture Victoria (2017) Growing lupin. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-lupin

MORE INFORMATION

[Sowing strategies to improve productivity of crops in low rainfall sandy soils]

[Lupin row spacing trial – Cowra 2007]

[Lupin row spacing trial – Merriwagga 2007]

Deep sowing will reduce the risk of pleiochaeta root rot, but increase the risk of hypocotyl rot.

The ideal compromise is to sow the lupin seed well below the soil surface, but into a furrow so that the seed is covered by a shallow layer of soil (e.g. by using press wheels). This way lupin seed is placed below the concentrated spore layer of pleiochaeta root rot, is not emerging through an excessive depth of soil, and so the risk of hypocotyl rot is minimised. [41]

3.8 Row spacing

Yield response to row spacing depends on stored soil moisture, soil type, spring rainfall, and weed control. In low-rainfall environments the yield rarely drops when the row spacing is increased to 60 cm. However, in high-yielding high-rainfall environments, or in very wet spring conditions, increasing the row spacing from even 15 cm to 30 cm can reduce the yield. [42]

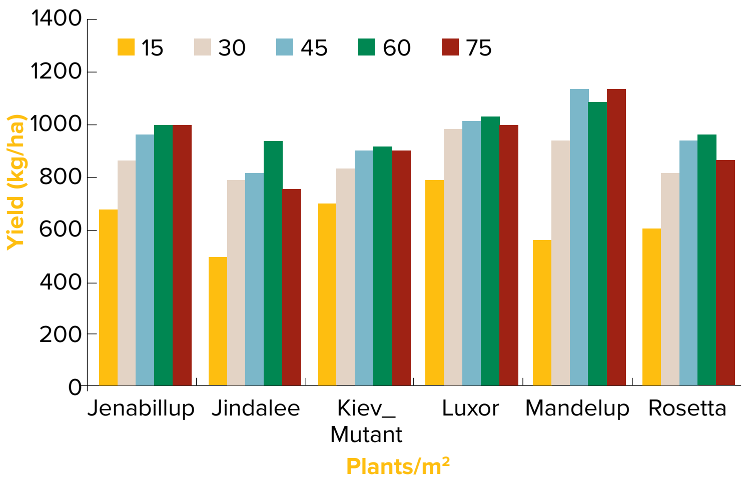


Figure 4: *Results of the I&I NSW VSAP (Variety Specific Agronomy Packages) trials, showing row spacing versus yield for different lupin varieties at Brocklesby (near Albury) in 2008.*

Source: NSW DPI

3.9 Sowing equipment

Key points:

- Tubulators or belt elevators are excellent for handling pulses as little or no damage occurs.
- Albus lupins can be direct drilled into cereal stubble using narrow points or disc seeders.
- On some airseeders the dividing heads may have to be modified because there is too little room in the secondary distributor heads to allow seeds to flow smoothly.

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

41 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

42 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Choosing a seeding system suited to growers' specific needs can have significant benefits in crop performance. Getting the seeder set-up right is critical for rapid seed germination, uniform crop emergence and good early vigour. Due to the diverse nature of soils and climatic conditions there is no one-size-fits-all solution.

3.9.1 Handling bulk seed

Augers with screen flighting can damage pulses, especially larger seeded types. This problem can be partly overcome by slowing down the auger. Augers with large flight clearances will cause less damage to large grains. Tubulators or belt elevators are excellent for handling pulses as little or no damage occurs.

Cup elevators are less expensive than tubulators and cause less damage than augers. They have the advantage of being able to work at a steeper angle than tubulators. However, cup elevators generally have lower capacities. Augering out of the header should be treated with as much care as the rest of the handling and storage process because it has the same potential for grain damage. Combine loaders, which throw or sling, rather than carry the grain can cause severe damage to germination.

3.9.2 Air seeders

An air seeder is a planter which has planting tynes mounted on a heavy duty frame, a central pneumatic seed and fertiliser delivery system, and a ground opener for seed and/or fertiliser placement (Photo 7). In most cases the sowing tyne will be followed by a press wheel that This method drags a tyne or knife-point through the soil and drop seeds in behind it with a press wheel at the back closing it up. The press wheel helps to cover the seed and aid with seed-soil contact.

This system offers many options and adaptations to meet a variety of conditions. The planter's main frame is carried on and controlled by wheels inside the frame. The attitude (fore - aft) levelling is controlled by caster wheels in front of the frame (floating hitch type).

This method of depth control is superior on land with sharp hills or gullies. When the ground opener type is chosen, the appropriate seed row finishing equipment must be installed on the rear of the air seeder.

Photo 7: *A New Holland T9 tractor with a Case Flexicoil PTX 600 airseeder bar towing a Flexi-Coil 3850 air cart bin used to sow seed.*

Source: GRDC

Airseeders with large single fluted rollers cannot meter pulses bigger than 18 mm without modifications to the metering roller (Photo 8). The dealer is the best person to consult about possible modifications. Significant levels of seed damage can be caused in airseeders by excessive air pressure, so be careful and use only enough air to ensure reliable operation.

Photo 8: *Conversion heads, such as this one for a Connor-Shea airseeder, allow large seeds to be sown with ease.*

Source: Grain and legume handbook

3.9.3 Disc seeder

No-till farming has brought new thinking to cropping and figuring out ways to sow into the stubble left from the previous crop has seen farmers turn to disc seeders.

In disc seeding, a metal disc rolls along the ground, cutting open a furrow like a pizza cutter, with a press wheel following behind to press soil back into the slot (Photo 9).

Photo 9: *A John Deere Disc seeder.*

Source: GRDC

Unlike air seeders, where straw and chaff are moved to the side as the openers and shanks pass through, the openers on disc drills must cut through crop residue. This allows disc seeders to handle much greater stubble loads than air seeders, which is a major advantage. Disc seeders leave the soil undisturbed and the soil surface relatively flat and free from deep furrows.

Disc drills cut through straw and anchored stubble does not usually cause plugging problems. Therefore, excessive crop residues create problems for disc drills by interfering with disc penetration into the soil and causing 'hairpinning' (forcing of uncut straw or chaff into the opener furrow). When hairpinning occurs, the straw and chaff 'pop-up' after the drill passes leaving the seed on the soil surface. Cutting coulters in front of the openers, residue manager or row cleaner attachments, down pressure on the discs, opener design, and sharpness of the discs all influence soil penetration and the ability of disc drills to cut through crop residues.

While Disc seeders can handle greater quantities of stubble, they can experience issues with pre-emergent chemicals and subsequent crop damage.

MORE INFORMATION

Disc seeders under the microscope

Bentleg opener seeding research

3.9.4 Disc seeders versus tyne seeders

In most cases, discs are better able to handle stubble, but tynes still have a strong following for a variety of reasons. The upshot is that no two farms are the same. Soil conditions, prevailing weather and farming preferences mean there are literally hundreds of different seeder setups, but there are some general rules of thumb (Table 8). [43]

43 J Law (2016) Disc seeders versus tyne seeders. The Weekly Times. http://www.weeklytimesnow.com.au/machine/crop-gear/disc-seeders-versus-tyne-seeders/news-story/773acc05475aa4d6bbb5a3622d23f444

Table 8: *Comparisons between Disc and tyne seeders.*

Factor	Disc seeders	Tyne seeders
Seeding	In ideal conditions, where the ground is firm but not compacted, a disc machine will achieve more consistent seed depth thanks to better contour following with the close vicinity of a depth gauge wheel. The disc cuts open a narrow slot and the seed is placed at the bottom against the wall, helping it achieve better germination. In less-than-perfect conditions, such as sticky mud and soft, sandy soils, discs are not so effective.	In less-than-ideal soil conditions a tyned seeder is capable of achieving consistent results. There is a much greater margin for error and in no-till seeding, tyned machines are widely used. Advancing tyne seeder technology is achieving similar results to discs in seed placement. Tynes are also better at incorporating pre-emergent herbicides and controlling grass weeds.
Sowing in stubble	Zero-till farming is the main driver behind disc seeder technology with a disc able to either cut through the stubble and trash or avoid it altogether as it creates a furrow. The challenge for discs is that they need to penetrate the soil and trash so the seed isn't just dropped on top, so the seeders can be much heavier and discs need to be kept sharp. They also don't work so well in soft, sandy soils or wet conditions where stubble stems can fold around the disc and be pushed into the furrow, an occurrence known as hairpinning, which restricts seed germination.	Tynes are not as good at getting through heavy stubble where length and quantity can cause it to clump up on the tyne, which leads to blockages. The operator then has to stop and lift the seeder to clear the blockage, then turn around to try to pass through that section again which can mean uneven seeding. Some areas will not be sown and full of weeds while another will be overseeded which leads to clumps of straw.
Soil Disturbance	Generally speaking, discs have less soil disturbance because the channel they cut through the soil can be as narrow as the thickness of the metal, so in situations where low disturbance is desirable, better results will be achieved. Less soil disturbance also means closer row spacings because there is little impact on neighbouring rows. However, discs can also be configured to achieve more disturbance, if that's what's desired, by setting them at an angle or doubling them up.	Dragging what is effectively a metal stake through the ground will disturb the soil and on average a tyne will throw more out each side meaning you can't have your rows too close together. However, tyne design is also advancing to reduce the amount of soil throw. They are also effective at cutting through compacted soil making them good for farmers who don't use controlled traffic farming. Tynes don't require as heavy a frame as a disc seeder to get through compacted ground.

Factor	Disc seeders	Tyne seeders
Wear and damage	A disc is mounted on bearings that can wear quickly in rougher ground and the disc itself will lose its edge. A disc seeder module is also more complex than a tyne setup, so there is more that needs monitoring. However, on rocky ground, the disc rolls over the stone rather than dig it up, which reduces impact and will achieve better seeding.	The knife point on a tyne also wears, but not as quickly and will still work effectively even when it's worn. They're also easier to replace. Breakout systems, which cause the tyne to flick up when a rock is hit, also help to reduce damage, although this can cause the seed to be scattered out the back. Hydraulic breakouts reduce this effect.
Cost	A disc seeder will be more expensive to purchase than a comparable tyned machine. The frames are heavier, the seeder modules more complex with rollers, gauge wheels and other contour-following technology. These costs are offset by the reduced amount of power (about 2hp per row less than a tyned seeder) needed to haul a disc seeder and the speed at which it can operate.	There is less complexity in a tyned machine so they are by nature much cheaper. They are easier to maintain, wearing parts such as knife points are cheaper to replace and manufacturers are happier to provide warranty on their machines. Some tyned machine makers also offer disc kits so a farmer can swap systems depending on conditions to make it a cost-effective best of both worlds.

Source: The Weekly Times

MORE INFORMATION

Disc v tyne seeder demonstration Illabo 2013

Making the change from tyne to disc

The following tips have been developed to support growers making the transition:

- Sow dry/early to overcome stickiness in clay soils: the more residue the less this will be a problem.
- Harvest management is critical: residues need to be spread uniformly so discs cut through an even layer of chaff.
- Harvest crops short, before using the disc for the first time to help with residue flow.
- In the first year using a disc system, sow deep, as the gauge wheel could ride high on the old tyne furrow.
- Row cleaners may be needed to level the ridges and furrows for your disc and gauge wheel. Consider a once-off harrowing or prickle chain to level paddocks to ease the transition from tyne to disc. Level paddocks are critical for good seed placement.
- If wet, wait until conditions dry a little for disc sowing.
- Consult your agronomist regarding pre-emergent herbicides. Also note that you cannot band urea when using discs.
- Standing stubble is better. Once you have mastered using discs, aim to cut stubble as high as possible (consider a stripper front). [44]

3.9.5 Setting up and calibrating the seeder

Seeder levelling

To ensure that all tynes are sowing at the same depth, adjust the machine on a level surface.

44 T Somes (2017) Sowing into stubble – why seeder calibration and set up is critical. GRDC. https://grdc.com.au/Media-Centre/Media-News/North/2017/03/Sowing-into-stubble-Why-seeder-calibration-and-set-up-is-critical

Coulter alignment

Pull the machine into the ground to check alignment. If alignment is out, raise the machine, slightly loosen the nuts on the coulter assembly and reposition using a straight-edge and a heavy hammer. Recheck in the ground. The next four adjustments must be made in the paddock after you have run the machine at the speed at which you propose to sow.

Tyne tension

Correct tension allows the tyne to vibrate, creating loose soil (tilth) while maintaining the correct point angle. Tyne tension should be in the range 260–400N. Use lower tensions on sandy friable soils. Too much tension results in excessive point wear. Depth Sowing depth is not as critical as the amount of loose soil over the seed. Check the depth to the bottom of the furrow after travelling at least 200m. The rule of thumb for depth is: ‘to the first knuckle of your index finger’. For early autumn or spring sowings, when warm, dry conditions after sowing are likely, this depth is necessary. In cold, wet winter conditions, sow more shallowly.

Tilth and speed

The amount of loose soil covering the seed is critical, regardless of the depth of the furrows. Aim for only 5–10 mm of loose soil over the seed. It is important to note that more seed fails to emerge by being buried under too much soil than by any other cause. There is too much tilth if less than 5% of the seed and fertiliser is visible in the furrow. Speed must be increased (up to 12 km/h) to throw more loose soil out of the furrow.

There is too little tilth if a high percentage of seed and fertiliser is visible in the bottom of the furrow. A single loop of heavy chain attached at either side of the seeder can be used to sweep soil from the edges into the furrow. Whatever device you use must follow the contour of the ground and not bulldoze loose soil on top of the seed.

In conventional seedbeds, deep seed burial is also likely, especially where the seedbed is loose and fluffy.

- Rolling to firm the seedbed before sowing is recommended for loose seedbeds.
- If using harrows, try to direct the seed tubes back so the seed lands in the last row of the harrows.
- When direct-drilling, a good rule of thumb is that 5% of the seed and fertiliser should be visible in the furrow.

Soil types and moisture

Often both soil type and moisture will vary within a paddock and as sowing proceeds. Try to sow different soil types in separate blocks and check the soil cover over the seed with changes in soil type. [45]

Calibration

A frequently neglected but essential part of any cropping program is accurate calibration of machinery. Seeder calibration is important for precise seed placement, and seeders need to be checked regularly during sowing. All seeders should be carefully calibrated before sowing starts. This should be done every season because seed size varies and machinery wear can alter rates.

The simplest method of calibration is as follows:

1. Place some of the seed to be sown in the planter box.
2. Unhook the seeding tubes and tie bags over the outlets in order to collect any seed which would normally go down the tube.
3. With the sowing mechanism engaged, drive the planter over a measured distance (D, metres) with a minimum distance of 100 m.

45 H Allan, E Havilah, H Kemp (1997) Establishing Pastures – Machinery. NSW DPI. Dairy Link. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/163123/establishing-pastures-1-10.pdf

4. Remove the bags of seed and weigh them on accurate scales (W, kg).
5. Measure the width of the planter in metres (P).

The formula for sowing rate is: = kg/seed per ha.

For example, if 0.61 kg of seed was collected from a 6-m wide planter over a distance of 100 m, the sowing rate would be:

= 10.17 kg seed/ha

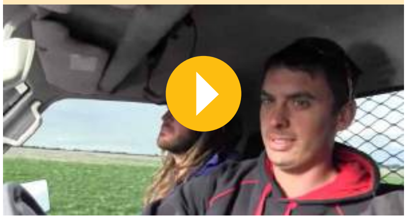
If there are a large number of sowing outlets, seed may be collected from a minimum of a quarter of them. In such cases do not forget to multiply the weight of seed collected from each outlet by the actual number of outlets. Sowing is the most critical operation in the cropping program. Too much seed leads to waste and a probable yield reduction, while too little leads to probable yield reduction. Make sure to take the time to calibrate accurately. [46]

Point maintenance

Seed placement and furrow profile can be adversely affected using worn points. Attention to point wear is essential, particularly when you are direct-drilling with narrow points that have to carve a channel through undisturbed soil. Expensive steel points can quickly become irretrievably ruined if they are not regularly hard-faced and maintained. An alternative in abrasive soils are cast points. [47]

VIDEOS

WATCH: Over the Fence North: Conditions are key to accurate seed placement



3.9.6 Sowing into stubble

Key points:

- Bar clearance and tyne layout influence a machine's ability to cope with heavy stubble loads.
- Select a seeder based on your farming system, cropping environment and financial position.
- Stubble management starts at harvest: height and residue spread will impact sowing.

When it comes to optimising winter crop establishment there are vital steps grain growers can take to improve planting outcomes, particularly when sowing into stubble.

Seeder blockages

One of the major challenges when working in a stubble retained system is blockages in sowing implements, particularly in irrigated and high rainfall zones, where yields and stubble loads are generally high. Blockages become an increasing issue when stubble loads are above three tonne per hectare (3 t/ha), or if chaff and straw hasn't been chopped and spread evenly at harvest.

Using seeding equipment designed for retained stubble systems will minimise blockages, but does require a significant capital investment. This research has also found modification to the profile and tyne layout of the seeder bar can reduce stubble clumping and blockages, and improve the machine's ability to cope with heavy stubble loads (ranging from 5–7 t/ha). Utilising inter-row sowing and wider row spacings has also helped growers sow through retained stubbles with greater ease. Disc seeders will cope with sowing into paddocks with much higher stubble loadings.

Seeder set-up and modifications

It is possible for simple modifications to be made to the seeder that will enable it to better cope with stubble. Seeder modifications that will enable sowing into stubble include:

- A straight rather than a curved shank will avoid residue building up.

46 T Price, B Beumer, P Graham, P Hausler, M Bennett (2008) Agnote: Machinery calibration: Boom-sprays, seeders and fertiliser applicators. DPIR NT https://dpir.nt.gov.au/__data/assets/pdf_file/0011/232967/711.pdf

47 H Allan, E Havilah, H Kemp (1997) Establishing Pastures – Machinery. NSW DPI. Dairy Link. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/163123/establishing-pastures-1-10.pdf

- Shanks with a rounded cross section have improved residue flow, compared to square shanks.
- Vertical or slightly backward leaning shanks promote a constant off-balancing effect on residue, reducing build up.
- Sudden changes of shape in shank profile inhibits residue flow and promotes clumping. High 'C' shapes, where the upper part of the 'C' is above the stubble flow work well.
- 'Stream-lined' designs with recessed bolt heads for point mounts also reduce residue catching.
- Existing curved shank tynes can be improved by retrofitting stubble tubes to make the face of the shank round and more vertical.
- Long knife-point openers can increase the effective vertical clearance of short tynes, but their break out rating needs to sustain the greater lever arm effect.
- Tyne shank add-ons (Pig Tails or other plastic/metal guards) improve trash flow around the tyne.
- Tread wheel residue manager's hold down the stubble beside the shank as it moves through.
- Row cleaners move stubble away from the disc to prevent hair pinning and assist in crop establishment.
- Residue pinning wheels (Morris Never-Pin wheels) hold the stubble on either side of the disc to assist in cutting ability.

Selecting a seeder when sowing into stubble

As part of the GRDC stubble initiative, Southern Farming Systems (SFS) has conducted extensive trial work on seeding system performance in relation to stubble retention. Key findings from this work include:

- Real time kinematic (RTK) guidance is a critical component to inter-row sowing
- Each seeder has varying capacity to handle retained stubble
- As a rule, discs handle higher loads than tyne and press wheel machines
- Wider tyne spacing across and along the bar will improve stubble handling
- Changing the angle of sowing direction slightly can minimise blockages
- Guidance auto steer on seeder bars will improve inter-row sowing
- Tynes and discs have varying degrees of soil throw and crop safety for pre-emergent herbicides
- Isolation of fertiliser from seed will limit seed burn. [48]

MORE INFORMATION

Sowing into stubble – why seeder calibration and set up is critical

Profitable stubble retention systems for the high rainfall zone

3.9.7 Sandy soil systems

Sandy soils present the highest risk of the soil drying out quickly and reducing germination.

Recent research work suggests the following strategies should be considered for more reliable crop establishment in sandy soils, where marginal moisture conditions are encountered:

- Place seed in contact with undisturbed soil moisture. This requires side banding or paired row banding able to place seeds on undisturbed ledges, or single shoot systems able to band seeds at furrow tilling depth. Deep furrow sowing capabilities may be required to reach moisture, or else growers can use low rake angle openers, low speed and compact seed banding systems to delve deeper.
- Minimise the fertiliser applied with seeds to control fertiliser toxicity, and use a double shoot system, with side or side plus vertical separation.

It is important to note that a lack of sub-seed disturbance may increase the severity of rhizoctonia damage on young seedlings, and the use of liquid banding technology to

48 T Somes (2017) Sowing into stubble – why seeder calibration and set up is critical. GRDC. https://grdc.com.au/Media-Centre/Media-News/North/2017/03/Sowing-into-stubble-Why-seeder-calibration-and-set-up-is-critical

combine in-furrow trace element application and fungicide protection at sowing may be necessary as part of a mitigating strategy.

Seed-fertiliser separation is particularly important in small seeded crops like canola for successful germination on sandy soils.

Obtaining high Seed Bed Utilisation (SBU) is important to manage fertiliser toxicity risks. In marginal moisture conditions, including non-wetting soils, it may be necessary to have full separation between seed and basal fertiliser, preferably banded at depth to maintain the maximum crop establishment potential.

Successful use of high SBU systems requires careful selection of equipment to suit growers' conditions.

When selecting for a higher SBU system, there are many factors to consider including single or double shoot, distinct split-rows or a wide band sowing, integrated opener design or wing attachment for an existing opener, and fertiliser placement relative to the seed zone.

In order to better establish crops in marginal soil moisture, it is important to select a design able to place seeds on undisturbed soil moisture, being aware that some systems will instead place seeds into furrow backfill, at greater risk of diluted moisture and potentially pre-emergent herbicide damage.

For more information about Fertiliser toxicity and optimising SBU, see Section 2: Pre-planting.

3.9.8 Managing herbicide toxicity

During the shift from conventional farming systems to no-till farming systems, the effective use of herbicides has become increasingly important. A well-planned herbicide strategy can mean the difference between making no-till work, or not. Recently it has become apparent that the rapid change in farming systems has overtaken farmer knowledge on how to use many herbicides in conservation farming systems.

Older, more traditional herbicides that were designed for use in cultivated systems can still be used effectively in no-till systems; however, they are usually used in a different manner. In addition, many herbicide labels (especially older type or generic herbicides) have the same content today as they did 10–15 years ago. Some products with generic counterparts have different label claims for the same active ingredient.

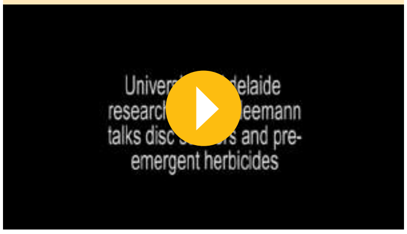
This creates problems for farmers and agronomists wanting to use these herbicides in our modern, no-till farming systems. Residual herbicides at sowing are very effective for controlling a wide range of weeds both in-crop and into the following summer. Some residual herbicides also have valuable knockdown properties. This is very useful, because knockdown herbicide options prior to sowing are limited for hard-to-kill weeds. Knowing the chemistry and mode of action of each herbicide is paramount to enable the best combination of crop safety and weed control. Heavy rainfall just after sowing when combined with certain soils can lead to crop damage. Some herbicides are mobile with soil water, while others are less mobile. Mobility can also change with time for particular herbicides.

The incorporation by sowing (IBS) application technique seems the safest way of using most residual herbicides, as the seed furrow is left free of high concentrations of herbicide. The soil from that furrow is thrown on the inter-row, where it is needed the most. In-furrow weed control is generally achieved by crop competition and/or small amounts of water-soluble herbicides washing into the seed furrow. For this reason, best results in IBS application occur when water-soluble herbicides are used either solely or in conjunction with a less-soluble herbicide.

Because of the furrow created by most no-till seeders, post-sowing pre-emergence (PSPE) applications of many herbicides are not ideal and are usually not supported by labels, as the herbicides can concentrate within the seed furrow if washed in by water and/or herbicide treated soil. Obviously, for volatile herbicides that need

VIDEOS

WATCH: Study sows the seed for best-practice with disc seeders



MORE INFORMATION

Seeding systems and pre-emergence herbicides

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incorporation following application, PSPE is not a viable option. Tyne seeders vary greatly in their ability to incorporate herbicides. There are many tyne shapes, angles of entry into the soil, breakout pressures, row spacings, and soil surface conditions. Each of these factors causes variability in soil throw, especially when combined with faster sowing speeds (>8 km/h). Consequently, residual herbicide incorporation is variable between each seeder. There are, therefore, no rules of thumb for sowing speed, row spacing and soil throw.

It is important to check each machine in each paddock. Disc machines show similar variability in their ability to incorporate herbicides. Disc angle, number of discs, disc size, disc shape, sowing speed, closer plates and press wheels all have an impact on soil throw and on herbicide-treated soil returning into the seed furrow. In all cases with tynes and discs, crop safety is usually enhanced by IBS rather than PSPE application of herbicides. [49]

Tyne seeders are reliably safest at ensuring crop safety, as long as the following guidelines are adhered to:

- Control speed to ensure no soil throw reaches adjacent furrows and the majority of herbicide is concentrated over the inter-row zone
- Ensure seeds are placed at sufficient depth with clean backfill to achieve adequate physical separation between crop seed and herbicide (known as ‘positional selectivity’).
- Create stable furrows to limit the risk of contaminated soils backfilling over time, and leaching of soluble herbicides into the seed zone.

Care must be taken with disc seeders when using pre-emergent herbicides. Trials in SA lower-north in 2012/13 showed that trifluralin significantly reduced wheat emergence with single discs, by up to 50%. However, using triple discs or applying Sakura® caused no damage.

The greater safety with triple disc systems is explained by their soil throw features being akin to a knife point system. Further, the inclusion of residue managers fitted ahead of the single disc openers significantly reduced crop damage. Growers should always follow herbicide labels to assess suitability for disc seeders. [50]

49 B Haskins (2010) Residual herbicides at sowing using disc and tyne no-till seeding equipment. Industry & Investment NSW. https://riverineplains.org.au/wp-content/uploads/2016/12/ResidualHerbicides.pdf

50 J Desbiolles, R Barr (2016) Selecting a seeding system for your soil. GRDC. https://grdc.com.au/Media-Centre/Media-News/South/2016/03/Select-a-seeding-system-for-your-soil

Plant growth and physiology

Key messages:

- Effective crop management depends on correctly identifying the growth stage of the crop. This is important for herbicide applications and harvest timing. The growth and development of the lupin plant are complex and overlapping.
- Lupins have epigeal emergence, where the seedling develops with its cotyledons above the ground. This means that they cannot be sown at deeper sowing depths as it requires a lot of energy to push the coleoptile out of the ground. Epigeal growth contrasts with many other legumes, such as field pea, chickpea and faba bean, which have hypogeal emergence.
- Lupin can be prone to pod abortion. For pod retention to be maximised, flowering needs to occur at a time that allows an adequate period for seed fill before the onset of dry hot conditions.
- Temperatures above 33°C cause abortion of flowers and pods. Very high temperatures above 36°C to 40°C will sterilise pollen, preventing fertilisation.
- Moisture stress before or during flowering has the largest effect on yield; causing flower abortion and reduced pod set. Severe moisture stress will shorten both the flowering and grain-filling periods.

The lupin species currently grown in Australia originated from a Mediterranean environment characterised by cool wet winters, followed by a rapid and sometimes early finish to the growing season brought about by low soil moisture levels and high temperatures. Early flowering is an advantage for Australian grain producers. Lupin is an annual legume (or pulse crop) that grows to between 20 and 150 cm high (Table 1). Narrow-leafed lupin can grow to over 100 cm tall, but it normally reaches a height of 50 to 80 cm. Albus lupin may grow up to 150 cm. Important early growth features on lupin plants include the cotyledons, petiols, stipule and growing point (Figure 1). The main structures of the lupin plant are the leaves, inflorescence (flower spike), branches, stem, roots, pods and seeds. [1]

Table 1: *Botantical characteristics of commonly cropped lupins.*

Species		Plant height (m)	Flower colour	Seed size (mg)
L. angustifolius	Annual	0.2 - 1.5	Blue, occasionally pink, white in domesticated forms	30–240
L. albus	Annual	0.4 - 2	White, pale pink, light blue, blue (var. graecus)	120–870

Source: Lupins.org

1 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

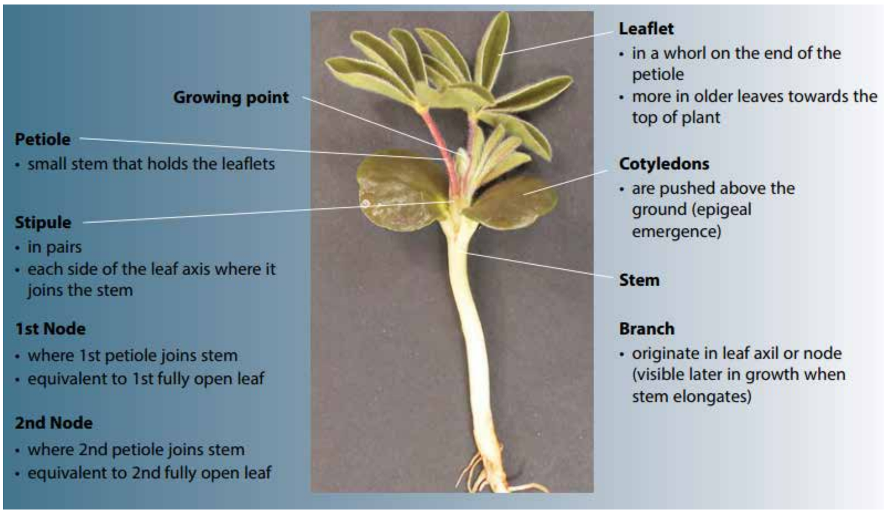

Figure 1: *Growth stages and components of albus lupin. Note that these stages and components also apply to narrow-leafed lupin.*

Source: NSW DPI

4.1 Plant growth stages

The growth and development of the lupin plant are complex and overlapping (Figures 2 and 3). Growth is the increase in the size and number of leaves, stems and roots, which produce biomass. Because growth is fueled by photosynthesis it is directly related to water use and light interception. Development is the process by which the plant moves from one growth stage to another. The rate and timing of plant development are determined by variety, photoperiod and temperature.

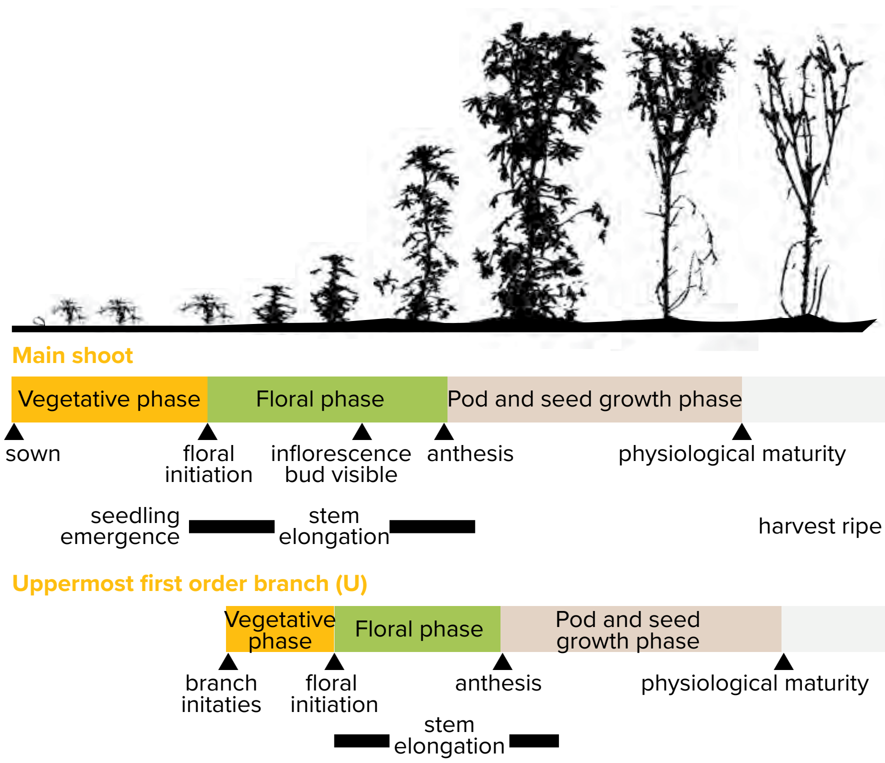

Figure 2: *Life cycle of the lupin plant.*

Source: NSW DPI

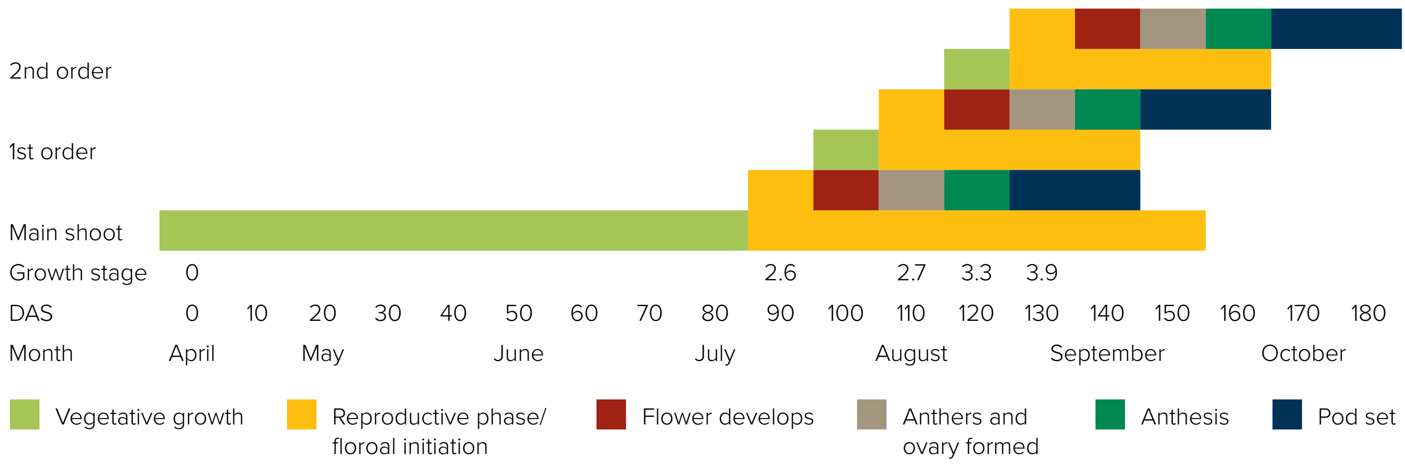

Figure 3: *Timing of growth stages after sowing.*

Source: Janet Walker, NSW DPI

Effective crop management depends on correctly identifying the growth stage of the crop. This is important for herbicide applications and harvest timing. A growth scale provides a common reference for describing these growth stages. The scale (Table 2) is similar to the Zadoks code for wheat. It is designed for assessing the development of the main shoot of individual plants. When assessing flower, pod and seed development, the lowest (most advanced) node of the main shoot inflorescence (flower spike) is used.

There are six stages: germination, leaf emergence, stem elongation, flowering, pod ripening and seed ripening. Each stage is subdivided into 10 units: for example, 0 to 0.9 covers germination and seedling emergence through to 5.0 to 5.9 for seed ripening. Some of the stages overlap, because vegetative and reproductive development occurs simultaneously. Where appropriate, throughout this book, a growth stage reference is provided for the development stage under discussion.

Table 2: *Lupin growth stages and numeral system. Adapted from Dracup and Kirby 1996*

Stage	Decimal Score
GERMINATION AND SEED EMERGENCE	0
Dry Seed	0.0
Start of imbibition (water absorption)	0.1
Radicle (root) protruding through the testa (seed coat)	0.3
Radicle 5 mm long (germination)	0.5
Hypocotyl protruding through the soil	0.7
Part of the seedling protruding through the soil	0.9
LEAF EMERGENCE	1
First pair of leaves protruding beyond upright cotyledons	1.0
1 leaf emerges from bud	1.1
2 leaves emerged from bud	1.2
3 leaves emerged from bud	1.3
4 leaves emerged from bud	1.4
5 leaves emerged from bud	1.5
7 leaves emerged from bud	1.7
10 leaves emerged from bud	1.10

Stage	Decimal Score
STEM ELONGATION	2
Little separation between bases of leaves	2.1
Bases of some basal leaves clearly separated	2.3
Bases of several leaves clearly separated from each other	2.5
Flower spike (inflorescence) bud clearly visible	2.7
Flower spike bud clearly separated from the base of the highest leaf	2.9
FLOWERING	3
Bracts completely hiding corolla	3.0
Pointed bud stage	3.1
Hooded bud stage	3.2
Diverging standard petal stage (anthesis)	3.3
Open flower stage	3.4
Coloured corolla stage	3.5
Senescent corolla stage	3.7
Floret abscised	3.8
Pod Set	3.9
POD RIPENING	4
Young green pod. No septa between seeds, seeds abutting	4.0
Seeds separated	4.1
Green pod, septa between seeds, slight bulging of walls, seeds filling 50% of the space between the septa	4.2
Seeds filling 75% of the space between the septa	4.3
Green pod, clear seed bulges in pod walls, seeds filling all space between septa	4.4
Green pod, septa split	4.5
Pod turning khaki-coloured	4.7
Pod pale reddish-brown and wrinkled	4.9
SEED RIPENING	5
Seed small, dark green with watery contents	5.0
Seed medium, dark green with watery contents	5.1
Seed large, dark green with watery contents	5.2
Seed large and soft, light green coat, no watery contents, green cotyledons	5.4
Seed light green to pale greyish-blue coat, green cotyledons	5.5
Green to yellow cotyledons	5.6
Pale fawn coat, yellow to golden orange cotyledons (physiological maturity)	5.7
Seed hard but dentable, mottling of pale fawn coat	5.8
Seeds hard and harvest ripe	5.9

Source: NSW DPI

4.1.1 Germination

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

1. water absorption
2. activation
3. visible germination.

Germination can take from 5 to 15 days, depending on soil temperature, moisture and depth of sowing. Variety has no effect on the length of this phase.

Phase 1 Water absorption - Growth stage 0.1

For a seed to grow it needs to absorb moisture. Germination occurs when the water content reaches about 60% of the imbibed seed weight. Lupin seeds are low in moisture. This means that the seed is capable of drawing water from soils that are very dry. As a result, the seeds can germinate in relatively dry soils. However, unlike in cereal crops such as oats, once germination starts in lupin it will not stop during moisture stress and then restart when the moisture returns.

Phase 2 Activation

Once the seed has swollen it produces hormones that stimulate enzyme activity, and metabolism begins. The enzymes break down the starch into sugars. Lupin seedlings rely on sugar and oil from the cotyledons as the main energy source at this first stage of growth. The storage proteins in the cotyledons are broken down to form the nitrogen and carbon (sugar) sources needed for initial development of the seedling.

Phase 3 Visible germination - Growth stages 0.3–0.7

The emergence of the radicle is the first visible sign of germination. When the radicle emerges it ruptures the testa near the hilum (Photo 1). The radicle is the first root and will grow down to anchor the plant in the soil. It then starts to absorb water and nutrients. The next process is extension of the hypocotyl away from the radicle towards the soil surface. The hypocotyl is the long, white length of stem that connects the cotyledons to the root system.

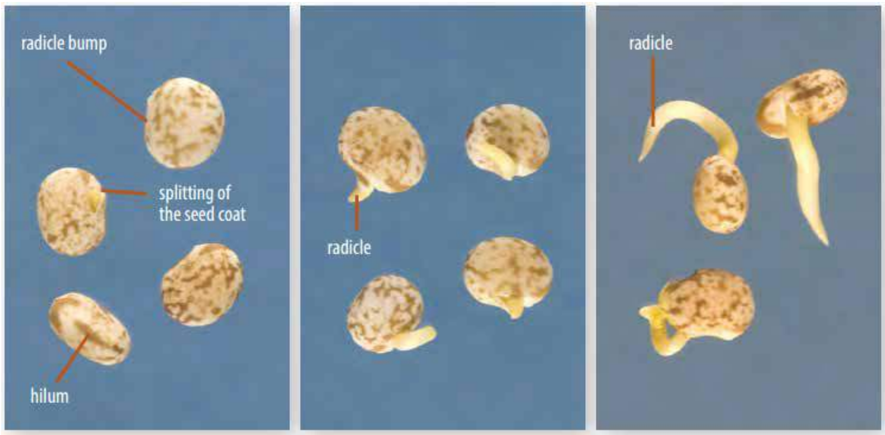

Photo 1: *Signs of visible germination in narrow-leafed lupin: swelling of the seed, splitting of the seed coat and emergence of the radicle. Photos: L Turton,*

Source: NSW DPI

For more information on factors affecting lupin germination, see Section 4.2 below.

4.1.2 Emergence

Lupin has what is called 'epigeal' emergence (Photo 2). An epigeal seedling develops with its cotyledons above the ground. This contrasts with many other legumes, such as field pea, chickpea and faba bean, which have hypogeal emergence.

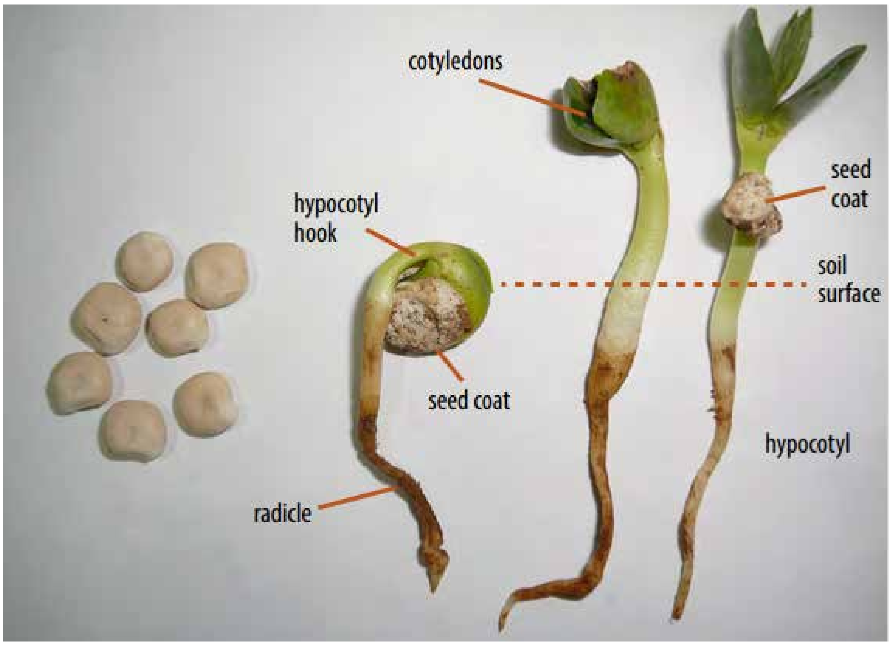

Photo 2: *In epigeal emergence the cotyledons are carried above the ground. The length of the hypocotyl indicates the sowing depth. Photo Janet Walker,*

Source: NSW DPI

While it is still below ground, the apex of the hypocotyl is bent over to form a hook. This hook protects the meristem (or growing point) and eases its passage through the soil. As the hypocotyl grows towards the soil surface, it pulls the cotyledons with it. They are pointed downwards and so protected. Often the seed coat is dragged to the surface as well. Obstruction of seedling growth (e.g. by surface crusting) keeps the hook closed and promotes lateral stem expansion to strengthen the emerging shoot (Photo 3). The hypocotyl is the first part to emerge from the ground, followed by the cotyledons. While the seedling is below the soil surface it remains pale or nearly white and the cotyledons do not expand.

Photo 3: *Emerging albus lupin (left). Note thickening of shoot from pressure of surface crusting. Emerging albus lupin seedling with seed coat (right).*

Photo: Janet Walker, Source: NSW DPI

When the hypocotyl reaches the light it stops lengthening, chlorophyll synthesis is stimulated and the cotyledons expand. After emergence, the cotyledons turn green and the first leaf grows out from between them. At the same time, further root formation occurs from branching of the radicle.

For more information on the factors affecting emergence, see Section 4.2.

4.1.3 Establishment

The plant is established once it has roots and a shoot (Photo 4). It is no longer relying on reserves in the seed, as it is producing its own energy. The leaves are now able to photosynthesise and the roots are able to take up water and nutrients. A crop is said to be established when 50% of seeds have germinated and emerged and are developing with strong seedling vigour.

Photo 4: *Established albus lupin.*

Photo: Jan Edwards, Source: NSW DPI

4.1.4 Leaves

Lupin has a palmate leaf structure with leaflets radiating from a central point. Slender, tapered stipules are located on either side of the petiole where it attaches to the stem. Lupin leaves are made up of leaflets. The leaflets are broad and rounded in albus lupin. Narrow-leafed lupin has narrow, pointed leaflets (Photo 5).

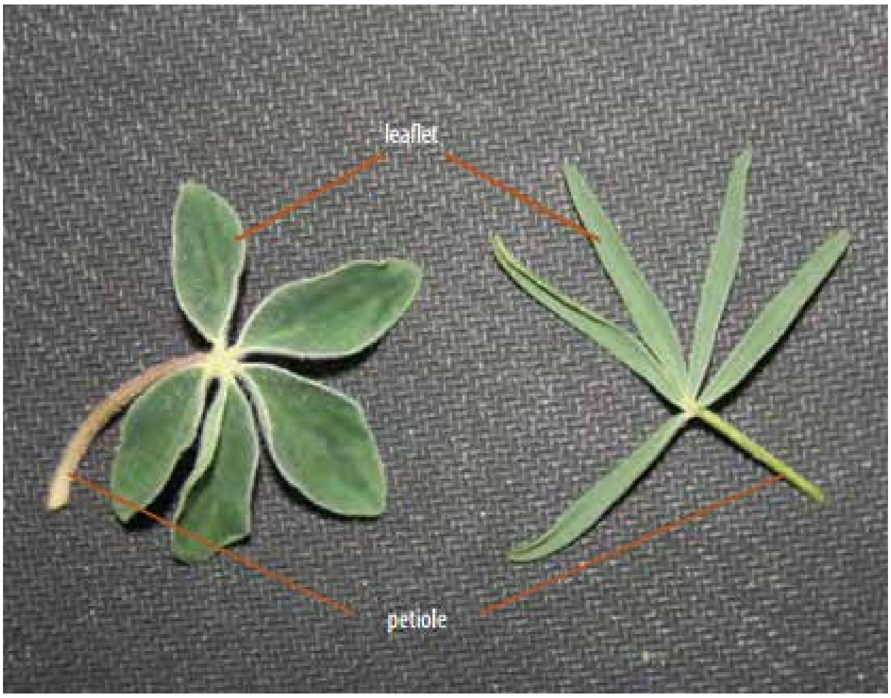

Photo 5: *Albus lupin leaf (left) and narrow-leafed lupin leaf (right).*

Photo: J Walker

The number of leaflets per leaf increases in number up the plant. The initial leaves contain five leaflets per leaf (Photo 6), whereas the top leaves can have between nine and 12 leaflets. The exact number of leaves on the main stem varies according to variety, location and sowing date. The lupin plant is heliotropic which means that the leaves turn throughout the day to follow the sun to maximise light interception. During the night, the leaves turn so that they are facing the rising sun in the morning. This continues until flowering commences.

Photo 6: *Three leaf (left), six leaf (5 leaflets per leaf - middle) and 12 leaf stages (right) in narrow-leaf lupin plant.*

4.1.5 Stems and branches

Lupin has an indeterminate growth habit, meaning that it can continue to initiate new lateral branches with flower spikes after it reaches the reproductive phase. This can occur when the plant has access to adequate moisture, nutrients and sunlight. Each branch is determinate and has a terminal inflorescence (flower spike). The pods on the branch all mature at approximately the same time. The main stem is the first to develop. The lateral branches form orders from the main stem (Figure 4). The first order is the branch arising from the main stem below the primary flower spike.

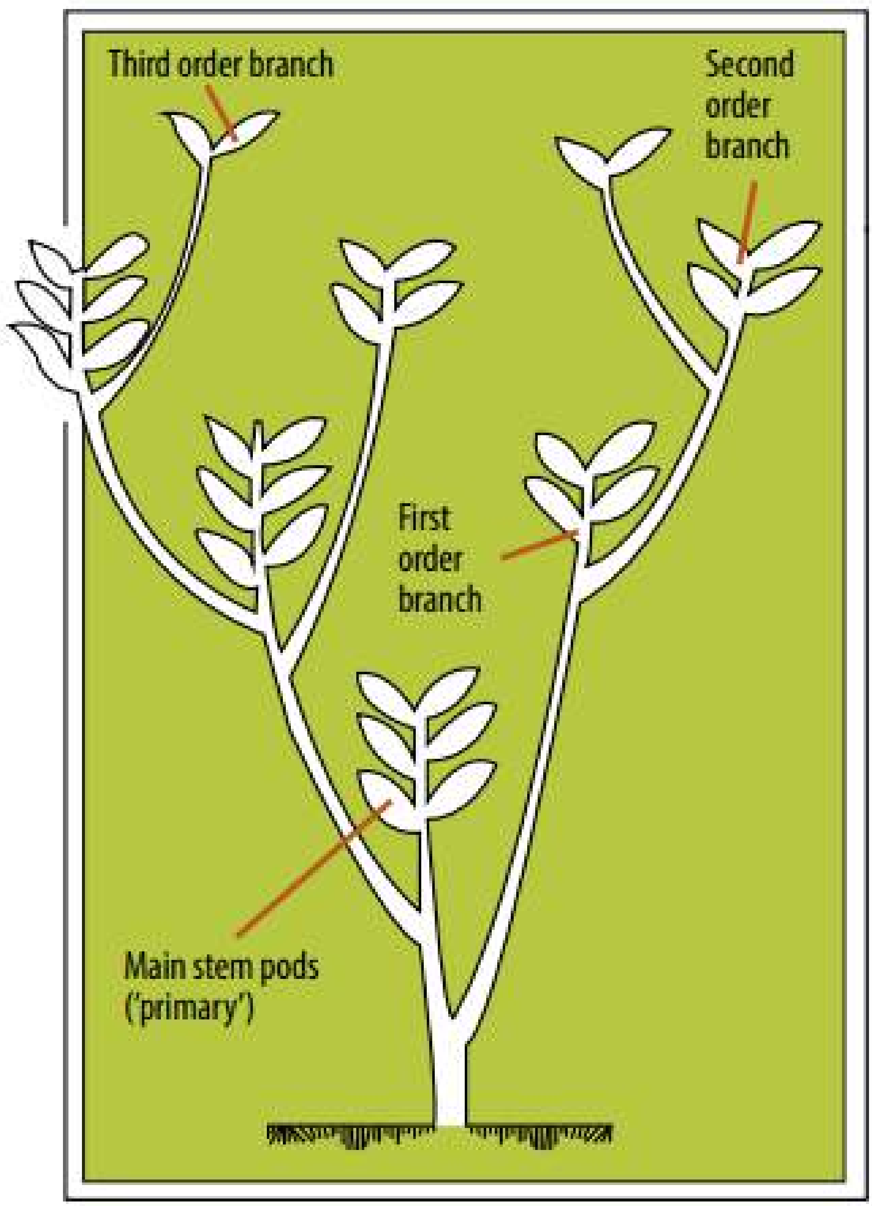

Figure 4: *Lupin plant showing branch orders and flowering.*

Source: NSW DPI

The lupin plant can have three or four orders of lateral branches in a good season, although in drier environments more than two orders is uncommon. To increase harvest index and yield, varieties have been bred to reduce internode length and therefore overall plant height. This reduces lodging and allows easier harvest. Breeding also aims to produce plants with short branches and earlier maturity, allowing the whole canopy to mature together.

4.1.6 Roots

Lupin has a strong taproot system, which is the primary root system. Lateral roots grow out from the taproot and form the secondary root system. The pattern and extent of lateral root growth depend on the species of lupin. Lupin is a pulse crop that can tolerate fairly acidic conditions, down to a pHCa of 4.5. In acid soils, the level of soil extractable aluminium is a better indicator of lupin yields than pH alone. Like all legumes, lupin forms nodules containing rhizobial bacteria, which fix nitrogen in the soil.

For more information on lupin nitrogen fixation, see Section 3: Planting – 3.1 Inoculation.

The depth to which lupin roots grow varies with the soil type. The roots of narrow-leafed lupin can grow up to 2.5 cm a day and reach lengths of up to 2.5 metres – deeper than those of peas and barley. The root system of lupin is much sparser than that of wheat, but lupin tends to have a greater proportion of the root system below 20 cm. Even though the root system of lupin is lighter than that of wheat, lupin can take up more water than wheat. The root hairs in lupin have less resistance to water flow than do the hairs of cereal roots. Soil factors – including temperature, moisture, nutrients and structure – all affect root growth. Root growth occurs best at soil temperatures of 18 to 22°C. Early-sown crops are likely to have more extensive root systems than later sown crops, simply because of the extra time available for growth.

Although both have deep taproot systems, narrow-leafed lupin is better adapted to extract water from deep in the soil profile, whereas the roots of albus lupin are better adapted to shallower, finer-textured soils.

Albus lupin species also develop proteoid roots that help them to take up phosphorus in acidic soils. Proteoid roots are short, lateral roots that develop when plant phosphorus levels are low (Photo 7). Proteoid roots release organic acids, mobilising not only phosphorus, but also iron, manganese and zinc in the rhizosphere and increasing their rates of uptake. They do not develop in soils with high levels of phosphorus.

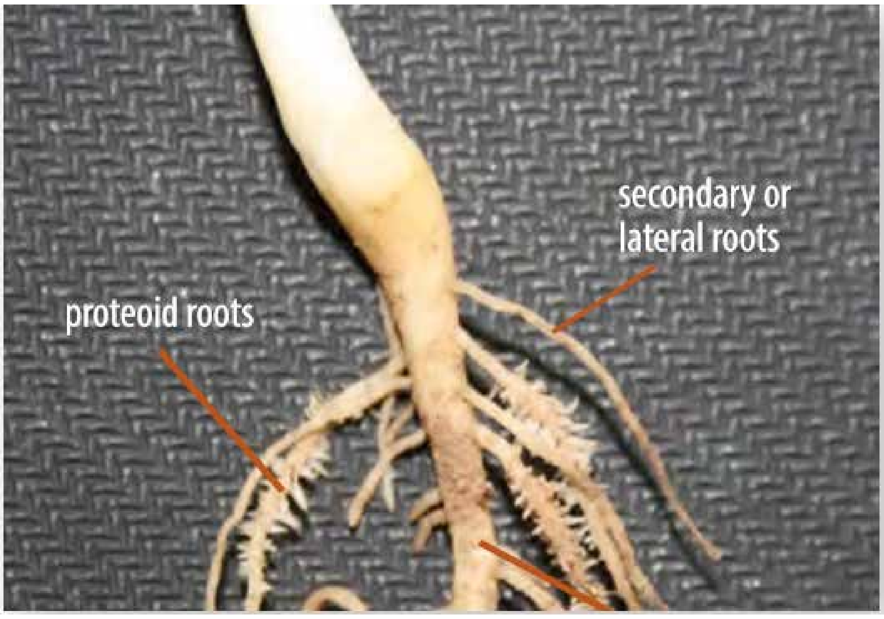

Photo 7: *Albus lupin seedling, showing proteoid roots developing on the secondary roots.*

Photo: J Walker, Source: NSW DPI

Healthy roots, unrestricted by soil constraints or disease, are essential to maximise yield. Lupin does not form associations with mycorrhizal fungi such as arbuscular mycorrhizae.

4.1.7 Reproductive development

The change from vegetative growth to reproductive development starts when the growing point of the main stem stops forming leaves and begins to produce flowers. This is called floral initiation. The phase continues until the flowers are pollinated and pod development begins.

After the main stem has switched to reproductive development, branches in the uppermost leaf axils of the main stem are formed and are still in the vegetative phase. The timing of this stage is determined by factors such as species, variety, temperature and daylength. Location and sowing date also have a significant impact on flowering time.

Vernalisation

Vernalisation is the accumulation of cold that triggers the switch to reproductive development. Plants that are vernalisation responsive will remain in the vegetative phase until they have experienced a certain number of 'cold' hours. Generally, lupin accumulates vernalisation at temperatures between 1°C and about 14°C. The number of cold hours or 'vernalisation response' required depends on variety. Inadequate vernalisation results in continued leaf production and no flowering at all. It can also create abnormal flowers with odd-shaped wings and petals that are narrower than normal. If vernalisation is delayed, pod fill is likely to occur later in spring when it is hotter and drier. The vernalisation requirement has been bred out of most narrow-leafed lupin varieties. This has created early flowering varieties adapted to Australian conditions. In these varieties, flowering time depends almost entirely on temperature and daylength. Varieties flower after producing a predetermined number of leaves on the main stem.

Lupin varieties that need vernalisation can be divided into two types: obligate and facultative. Obligates need vernalisation to flower and include varieties such as Jindalee⚴. Facultative types will flower eventually without the cold requirement, but they will flower much faster with vernalisation. Examples are Luxor⚴ and Rosetta⚴. The albus varieties Kiev Mutant and Ultra have the Brevis gene for early flowering. Kiev Mutant has no vernalisation requirement, whereas Ultra responds partly to vernalisation.

4.1.8 Flower spike

Lupin produces a flower spike (raceme) on the end of each branch; this is referred to as a terminal flower spike. Each flower spike is made up of many individual flowers. Narrow-leafed lupin flowers are white and tinged with pink or purple while albus lupin flowers are white tinged with blue. Each flower has five petals, like all the flowers in the Fabaceae family. Flowering starts at the base of the flower spike and continues up the stem.

In NSW, lupin usually flowers 100 days after sowing. However, this can vary by as much as 30 days depending on seasonal conditions. Daylength also has an effect. Lupins flower earlier in northern NSW because temperatures are higher and days longer during winter.

It usually takes about 40 days, depending on the environment and the variety, for flower primordia to develop into a mature flower. A lupin plant will flower for 4 to 8 weeks, but an individual raceme usually flowers for only 10 to 14 days.

Pollination and fertilisation

Pollination and fertilisation follow pollen release. Pollination is the process in which pollen grains are forced into contact with the stigma.

Most lupin pollination does not require a pollinating agent, as the pollen comes into contact with the stigma on its own. However, the flowers can be tripped (a pollen dispersal mechanism of legumes whereby the stamen is exposed) (Photo 8) when a large enough insect lands on the flower, causing the style and stigma to protrude from between the wing petals. During the tripping the stigma may be pollinated with either the plant's own pollen or pollen carried on the insect from another flower. Lupin flowers attract insects by their colour, pollen, and scent. The flowers contain large amounts of pollen but do not contain nectar. Most lupin pollination does not depend on the flower being tripped. Lupin pollen is too large to be carried on the wind.

Photo 8: *A bee tripping and pollinating an albus lupin flower.*

Photo: Lowan Turton in NSW DPI

Narrow-leafed lupin is self-pollinating, because pollen release occurs just before flower opening. By the time the flower is open for insects to visit, the stigma is already covered with its own pollen. Although insects still visit the flowers, their visits do not increase the pod set or yield, so the amount of cross pollination is very low. This means it is easier to keep varieties pure.

Albus lupin has a pollination mechanism similar to that of narrow-leafed lupin, but cross-pollination is more frequent. Cross-pollination in albus lupin occurs only at low levels (10% to 15%). Thus, newer varieties of albus lupin must be grown separately from the older varieties to prevent cross pollination and maintain their low seed alkaloid levels. The albus lupin industry has set a zero bitter (high alkaloid) contamination level.

For more information on bitter seed contamination levels, see Section 2: Pre-Planting – Seed quality.

4.1.9 The pod

Pod and seed development actually begins before flowering. The developing flower contains tissues that will eventually be part of the pod and the seed. After pollination and fertilisation the pod begins to grow (Photo 9).

Photo 9: *Pods develop further after pollination.*

Pod set is the process undergone by a fertilised ovary before it starts to grow rapidly to form a pod. Not all flowers on a flower spike form mature pods, and not all set pods survive to maturity. Natural shedding of flowers and young pods is common in many species of grain legumes.

When the developing pod is 8 to 10 mm long, the pod is considered set and is unlikely to abort. Each pod contains between two and six seeds. The walls of the pod thicken and act as an energy store for the seed as it grows. The pod walls of narrow-leafed lupin are thinner than those of albus lupin and dry faster at harvest. In lupin, the outside of the pod makes up a greater proportion of the total pod weight at maturity than in other legumes such as soybean.

As the pods approach maturity they begin to dry out and change colour from green through tan to a light reddish brown (Photo 10).

Photo 10: *Pods at growth stages 4.4 (right) and 4.9 (left). Photos: Janet Walker (left) and Jan Edwards (right),*

Source: NSW DPI

Pod abortion

Even if the flower is fertilised, some pods may fail to develop, in which case they are usually aborted from the flower spike. Most pods that set survive to maturity, but a few may abort after pod set. A period of pod abortion from fertilised flowers occurs 10 days after pollen release.

The pod retention rate is the number of pods that survive to crop maturity. When pods abort after pod set, they may remain attached to the plant but do not produce viable seed. For pod retention to be maximised, flowering needs to occur at a time that allows an adequate period for seed fill before the onset of dry hot conditions. Seeds can also abort. This often occurs in the early stages of their growth.

Some pods can remain and continue to grow but do not develop seeds. The number of pods that develop seeds is highest at the bottom of the flower spike, and the probability of pods being set decreases towards the top. However, environmental stress during flowering or initial pod development can result in gaps between pods along the flower spike.

4.1.10 The seed

Seed enlargement begins after fertilisation. Five or six seeds develop per pod. The seed rapidly increases in size as the cells divide and expand. During this time, there is little increase in seed weight. The developing seeds are green. Cutting the seed open lengthwise soon after pod set reveals a small embryo and radicle. The space in the embryo sac is filled with endosperm (jelly-like material around the embryo). When squashed, the seed appears to contain only water. Seed growth lasts for 38 to 72 days. During seed fill the seed coat is green. By the end of this phase the cotyledons have become firm and the radicle of the embryo has turned white. This indicates that the seed is approaching physiological maturity.

Physiological maturity is the stage at which the seed-filling period has ended and the seed has reached its maximum dry weight. The cotyledons turn from yellow to golden brown. The halves of the pods turn tan to light brown. Physiological maturity of the whole plant occurs when more than 90% of the pods on the highest order branch have reached maturity. After physiological maturity, the seed dries down further.

For more information on harvest maturity, see Section 12: Harvest.

The lupin seed (Photo 11) is made up of several parts. Lupins have a typical dicotyledon structure. Their thick seed coat (hull or testa) comprises about 25% of the seed weight for narrow-leafed lupin and 15% for albus lupin. This is higher than in most domesticated grain species. The thick seed coat is mostly cellulose and hemicellulose, means that it is important to consider the composition and nutritional value of their cotyledons (kernel). [2] Seeds vary in colour from white to brown depending on the variety.

Photo 11: *Narrow-leafed lupin seed (left) is smaller than albus lupin seed (right).*

Photo: Jan Edwards, Source: NSW DPI

There are several layers in the testa, which surrounds the embryo. The embryo has two main parts, the embryo shoot, which grows up to form the plant, and the radicle, which grows down to form the root system. Each seed has two cotyledons, which nourish the embryo during germination and emergence.

Lupin seeds have two distinct marks on the outside. The hilum is the scar left when the seed separates from the seed stalk in the pod. The small bump below this is the radicle bump; the radicle will emerge from this bump at germination. Lupin seed is valued because of its high protein, high digestibility and low starch levels. The amount of protein depends on the species and variety and where it is grown. The high protein level makes lupin seed highly desirable for animal rations. Narrow-leafed lupin is particularly suited as feed for ruminants and single stomached animals such as pigs and horses, and as a feed in aquaculture. Albus lupin is more suited to feeding ruminants than single-stomached animals because of its high seed manganese levels, which limit the growth of single-stomached animals.

For more information on the qualities of lupin for animal consumption, see Section 2: Pre-planting, Lupins for feed grain.

Wild lupin seeds contain high levels of quinolizidine alkaloids. These alkaloids are part of a natural defence mechanism against insects and other herbivores. They are also thought to give some stress tolerance. However, alkaloids produce a bitter taste

2 http://www.lupins.org/feed/

and are highly toxic. Alkaloids have been bred out of most commercial varieties of lupin, except the lupini bean, which is grown specifically for its bitter seed. Narrow-leafed lupin is free of bitter seed. However, seed from older albus lupin varieties can contain up to 3% quinolizidine alkaloids. [3]

4.2 Germination and emergence issues

Successful crop establishment depends on a number of factors, including soil moisture, temperature, aeration, soil crusting, disease or seed quality. It is important to get the correct conditions for good crop establishment. Delayed emergence increases the risk of pathogen attack, predation and low seedling vigour. Ensure the rates of fertiliser are used to protect the seed, avoid residual herbicide carryover and use adequate inoculation.

4.2.1 Moisture

Moisture is vital for lupin establishment, as it influences how many days it takes for a plant to emerge. Emergence is more sensitive than germination to soil moisture levels (Figure 5). Low soil moisture reduces the extension of the hypocotyl and increases the growth of the radicle. This increases the supply of moisture to the seedling but restricts emergence. A lupin seed that has partly imbibed and then dried out will have reduced viability. This has implications when sowing into soils with marginal moisture.

Sowing into hardsetting or crusting soils that dry out after sowing may result in poor emergence. The hard soil, which has high strength, makes it difficult for the hypocotyl to push through the surface. Too much water can inhibit germination and early root growth. Oxygen is essential for seed germination. When soils become waterlogged, the oxygen supply in the soil solution rapidly decreases. Lupin will not germinate in waterlogged soils, and seed survival may be reduced to zero after as few as 4 days. Waterlogged soils also severely restrict the growth of the main and secondary root systems. Soil moisture at 50% of field capacity gives the best main root growth at establishment.

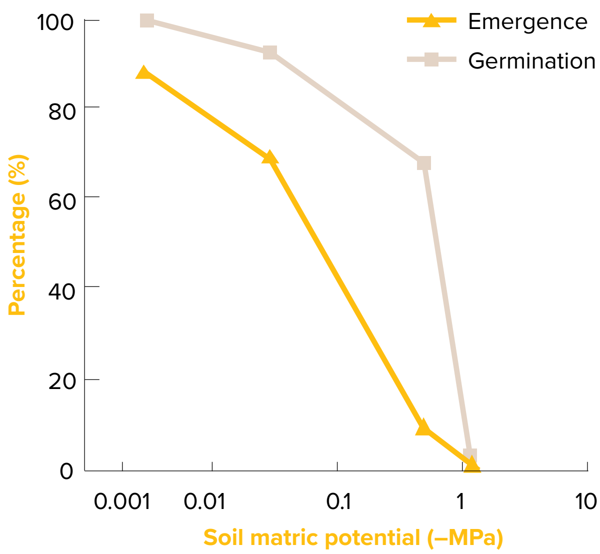

Figure 5: *Effect of moisture on the final germination and emergence percentage of narrow-leafed lupin. A matric potential of about 1 MPa is essentially air dry, whereas 0.001 MPa is saturated.*

Source: Modified from Dracup et al. (1993), in NSW DPI

3 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

4.2.2 Seed dormancy

Wild lupin species have adapted to drought by producing seeds with coats that are impermeable to water (i.e. hardseeded). This prevents germination of a large proportion of seed in any given year and makes sure that the species will survive when seed production fails, such as after a drought. These hard-seeded species need temperature changes or scarifying to crack the seed coat before germination can begin. The seed of some wild species of lupin also contains inhibitors that must be leached out by water before germination will occur. This also prevents germination without adequate soil moisture. Domesticated lupin varieties are bred to contain a particular gene (called 'mollis') that makes the seed coat permeable to water, ensuring good germination. [4]

The rate of germination and emergence is also greatly influenced by temperature;, for more information, see Section 1.3.1 below.

Seed size, seed quality and the way that seed has been handled and/or stored can also impact the rate of germination and seedling emergence. For more information, see Section 2: Planting - Planting seed Quality.

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

The maturity or length of time taken for a variety to reach the start of flowering depends on the thermal time (accumulated temperature), photoperiod (daylength), vernalisation (cold requirement), species and variety. There are differences in maturity among lupin species and varieties, but they are not as great as among, for example, wheat varieties. Lupin varieties are generally ranked in maturity relative to that of Kiev Mutant, as this is one of the earliest varieties to flower. For example, where Kiev Mutant is the first to flower it is usually followed by Wonga⦻, then Luxor⦻ 7 days later, Jindalee⦻ 10 days later than Kiev Mutant, and Rosetta⦻ 11 to 14 days later.

4.3.1 Temperature

Lupin will grow in temperatures between 0°C and 40°C. The optimum temperature for photosynthesis is between 10 and 22°C (Table 3). Above 22°C, photosynthesis, and therefore growth rates, tend to slow. Cold temperatures reduce growth. Fewer leaves form on the main stem at 10°C than at 18°C. Temperatures below 7°C restrict nodulation and nodule development and hence plant growth.

Table 3: *Temperature ranges for the development and photosynthesis of lupin.*

	Minimum (°C)	Optimum (°C)	Maximum (°C)
Phenology	0	20	30
Photosynthesis	0	10–22	40

Source: Dracup et al. 1993, in NSW DPI

Thermal time

Thermal time is a way of expressing accumulated temperature. It is calculated as the mean daily temperature minus a base temperature and is recorded as degree-days (°Cd). The base temperature is the minimum temperature at which the plant grows, and this varies for each crop. Thermal time varies from year to year in the same location. Thermal time is the main influence on the timing of development. For example, first order branches flower 164 to 244 degree days later than those on the main stem (i.e. 11 to 16 days later at 15°C). The total number of degree-days required to reach a specific growth stage can be calculated (Table 4).

4 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Table 4: *Approximate degree-days for the main development stages.*

Development Stage	Thermal Time (Degree-Days)
Crop emergence	20°Cd
Appearance of each main stem node	40°Cd
Emergence to end of juvenile phase	360 – 375°Cd
End of juvenile phase to floral initiation*	560 – 665°Cd
Floral initation to flowering	135 – 140°Cd
Emergence to flowering	495 – 1160°Cd
Flowering to start of grain filling	500°Cd
Start of grain filling to maturity	500°Cd
Emergence to maturity	2260°Cd

* For daylength equal to, or shorter than, 10.8 h

Source: Dracup et al. (1993); Dracup and Kirby (1996a, b); Farre et al. 2004, in NSW DPI

Heat and cold stress

Heat stress alone does not appear to affect the rate of photosynthesis or leaf drop (abscission). However, heat stress does affect pod development, seed number and seed weight. Heat stress, in the form of short bursts of high temperatures (>30°C) can reduce the size of individual seeds and therefore final yield. Bursts of high temperature early in seed filling can cause seed abortion. During the later stages of seed fill, high temperatures can reduce the weight per seed in lupin. High temperatures at flowering cause greater yield loss than at any other growth stage. Temperatures above 28°C reduce pollen tube growth and can cause sterility. This reduces the number of flowers that are fertilised, which in turn reduces the number of pods set. Temperatures above 33°C cause abortion of flowers and pods. Very high temperatures above 36°C to 40°C will sterilise pollen, preventing fertilisation. Moisture stress makes the effects of temperature worse.

Actively growing tissues tend to be more sensitive than dormant tissues to low temperatures. Lupin can be damaged by frost during vegetative growth, although the leaves enclosing the meristem give some protection to the vegetative shoot tips. Lupin grown in the paddock acclimatises to low temperatures by exposure to cold over several days. Cold-hardened plants may then suffer injury at slightly colder temperatures. The length of time the plant is exposed to cold also has an important influence on the level of damage. The roots of albus lupin growing 10 cm below the soil surface can survive temperatures as low as –3.5°C.

For more information on heat and cold stress, and frost damage in lupin, see Section 14: Environmental issues.

Effect on germination

Germination depends on temperature. The optimum temperature for the germination of lupin is 20°C. The speed of germination depends on the accumulated temperature, which is measured as degree-days. Degree-days are the sum of the average daily temperatures over consecutive days.

The rate of germination increases linearly to 20°C, then declines. At 20°C, germination takes between 24 and 36 hours (1–1.5 days). This equates to about 27 degree-days. At temperatures greater than 23°C, germination can be highly variable. At temperatures above 30°C germination is very low (Figure 6). Germination is unlikely at temperatures greater than 33°C.

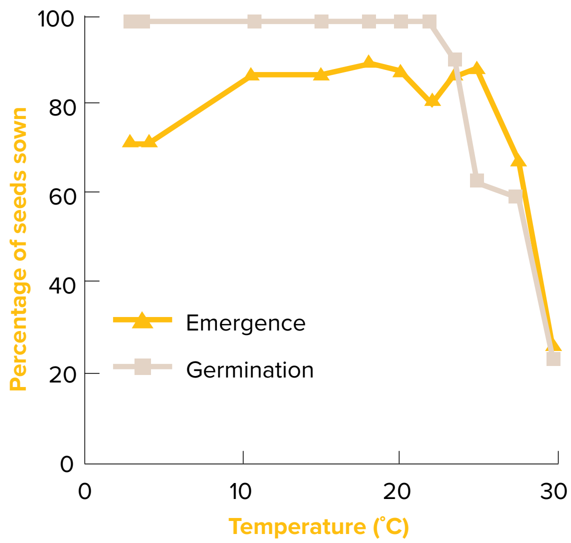

Figure 6: *Effect of temperature on final germination and emergence percentage of narrow-leafed lupin.*

Source: Modified from Dracup et al. (1993) in NSW DPI

Effect on emergence

Plant emergence and establishment are the starting points for crop growth. Maximum emergence occurs between 10 and 20°C. At 20°C, for example, narrow-leafed lupin takes 4 to 4.5 days to emerge from a depth of 4 cm. This equates to 75 degree-days. For every millimetre deeper the seed is planted, emergence will take about 2 degree-days longer.

High temperatures during establishment can cause seedling death, reducing the number of plants that establish. At temperatures between 20°C and 25°C, seedlings generally fail to emerge, because splits or breakages occur in the radicle or hypocotyl. Above 27°C, emergence failure occurs mainly because of problems with seed rotting and disease.

In hot environments, the maximum temperature in the top few centimetres of the soil can be 10°C to 15°C higher than the maximum air temperature, especially with a dry, bare soil surface and high radiation intensity. Under these conditions, soil temperatures can reach 30°C, seriously affecting seedling emergence.

Figure 7 shows the probabilities that the 9 am soil temperature at a depth of 10 cm at Cowra, NSW, will be greater than 20°C and that the daily maximum air temperature will be greater than 30°C. [5]

5 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

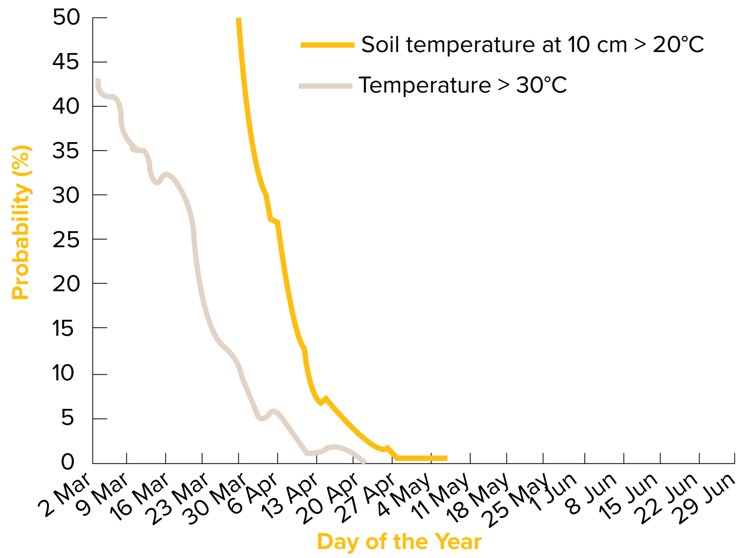

Figure 7: *Probability that the 9 am soil temperature at a depth of 10 cm is greater than 20°C and the daily maximum air temperature is greater than 30°C; Cowra, NSW (1960–2009).*

Source: NSW DPI

4.3.2 Photoperiod (Daylength)

Photoperiod or day length is the duration (number of hours) of exposure to daylight. Lupin (like wheat) is a long-day plant, meaning that it responds to increasing photoperiod. Increasing daylength provides a signal for the start of reproductive development. When lupin is grown with increased daylength, the time from sowing to flowering is shorter. There is also an interaction with temperature.

The number of days to flowering is less with longer daylength. At 10°C, the number of days to flowering is ~32 days less with the longer daylength than with the shorter one. The number of days to flowering is also less at the higher temperatures. The number of days to flowering is ~23 to 53 days less at 16°C than at 10°C (Figure 8).

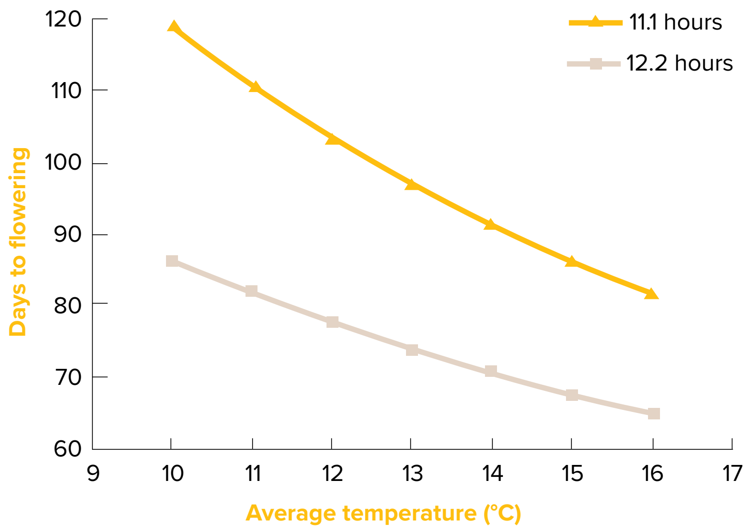

Figure 8: *Predicted days to flowering for lupin variety Gungurru grown under different temperatures and two different daylengths (Triangle = 11.1 hours and Square = 12.2 hours).*

Source: Reader et al. (1995), in NSW DPI

Increasing daylength also increases the rate of leaf area expansion, increases dry matter production and increases stem height. There is no impact on the number of leaves or branches on the main stem with increasing daylength. [6]

4.3.3 Light intensity

Light intensity can also affect plant growth. Reduced light intensity during cloudy weather can reduce photosynthesis. This can outweigh the effects of daylength (photoperiod) and can increase the time taken for lupin to flower.

4.3.4 Moisture

Moisture stress before flowering (from growth stage 2.5) or during flowering has the largest effect on yield. It causes flower abortion and reduced pod set. Severe moisture stress will also hasten the onset of flowering, shortening both the flowering and grain-filling periods.

Lupin is less able to make osmotic adjustments than wheat and other pulse crops such as chickpeas and lentils. This makes lupin less able to keep metabolising when there is a severe plant tissue water deficit. As a water deficit develops, branch growth slows and carbohydrates (assimilates) are diverted from vegetative growth to reproductive development. The deep roots of lupin allow it to access soil water from deep within the soil profile.

When there is plenty of soil water the lupin leaves track the sun. If water deficits begin to develop, the leaves roll to minimise the interception of radiation. Wilting can also occur, but at a higher water potential than in wheat. If moisture stress occurs, growth rates can recover fully if the plant later receives enough moisture. [7]

For more information on the effects of waterlogging on lupin growth, see Section 14: Environmental issues.

6 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

7 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Nutrition and fertiliser

Key messages

- Crop nutrition is a major determinant of profitable crop production, with both under and over-fertilisation leading to economic losses.
- Soil and plant tissue sampling are important tools in maintaining paddock nutrition.
- Manganese, phosphorous, sulfur and nitrogen (and minor elements like zinc) will assist lupin crops to reach their full potential but be aware of toxicity issues when starter fertiliser is placed with the seed.

Fertiliser applications are the largest single variable expense for grain growers producing a crop (13% of total costs in 2010–11), but nutrition (e.g. nitrogen, phosphorus, potassium, sulfur and micronutrients) is a major determinant of profit. [1] Inefficient or incorrect use of fertiliser can be a substantial, but somewhat hidden, cost in the cropping operation.

Lupins have vigorous tap roots to access nutrients, however root development may be impeded by sub-soil constraints. Under such conditions, fertiliser application may be beneficial to lupin growth. [2]

Albus lupin species also develop proteoid roots that help them to take up phosphorus in acidic soils. Proteoid roots are short, lateral roots that develop when plant phosphorus levels are low. Proteoid roots release organic acids, mobilising not only phosphorus, but also iron, manganese and zinc in the rhizosphere and increasing their rates of uptake. They do not develop in soils with high levels of phosphorus.

Also, be aware that lupin is sensitive to fertiliser toxicity. When sowing lupin, fertiliser application methods and rates need to be considered to avoid damaging seed and subsequent establishment. Lupin is more tolerant to aluminium and manganese toxicity than other pulse crops.

For more information, see Section 4: Plant Growth and physiology – section 4.1.6 Roots.

Using good data to better understand your existing soil nutrient status before deciding on a fertiliser strategy can optimise expenditure on fertiliser and crop yields. Be sure to consider the following:

- Fertilisers are a major cost of growing a crop.
- Ensure your adviser has, or is working towards, the Fertcare Accredited Adviser standard.
- Be clear on fertiliser product choice and rate and timing of application.
- Soil testing is the only quantitative nutrient information that can be used to predict yield response to nutrients.
- Soil samples should be taken before sowing so that results and recommendations are available in time to order the right fertiliser product(s).
- Choose a laboratory that has the Australasian Soil and Plant Analysis Council (ASPAC) certification for the tests they offer. National Association of Testing Authorities (NATA) accreditation is also desirable.
- Regular planned sampling of paddocks (for example, every three years) allows monitoring of fertility trends over time.

Crop production is becoming increasingly precise, but when it comes to fertiliser application, some growers often make decisions about type, time and rate based on incomplete information or a 'best guess'. Robust fertiliser decisions can be made by

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1 GRDC. More profit from crop nutrition. https://grdc.com.au/research/trials,-programs-and-initiatives/more-profit-from-crop-nutrition

2 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

MORE INFORMATION

Better fertiliser decisions for crop nutrition

Winter Crop Nutrition Ute Guide

checking the 'four Rs' of plant nutrition, an approach developed by the International Plant Nutrition Institute that has become the cornerstone of nutrient stewardship in many countries. 4R Plant Nutrition is built around the right fertiliser source, applied at the right rate, at the right time, and in the right place. [3]

For more information, see Section 2: Pre-planting, Section 2.3.5 Safe rates of fertiliser at sowing.

5.1.1 Winter Crop Nutrition Ute Guide

The Winter Crop Nutrition Ute Guide is designed to help farmers, advisers, researchers and students identify nutrition disorders that they are likely to encounter when monitoring crops across Australia. It covers both nutrient deficiencies and toxicities and environmental, chemical and physiological disorders which can give similar symptoms to nutrient disorders. An emphasis has been put on ease of diagnosis with disorders giving similar symptoms being placed together.

With more frequent use of opportunity cropping, improved farming techniques and crop rotations, and higher yielding varieties, nutrition programs should be reviewed regularly. Common nutrient deficiencies are nitrogen (N), phosphorus (P), potassium (K) and zinc (Zn), while sulfur (S), copper (Cu) and molybdenum (Mo) may be also be lacking in some soil types and growing areas. Molybdenum (Mo) deficiency and manganese (Mn) toxicity can occur in more acidic soils.

Soil testing, plant analysis and paddock test strips should all be part of a regular nutrition monitoring program for each paddock so that corrective action can be taken before significant yield loss occurs. In most cases when visual symptoms of nutrient disorders appear large yield losses have already occurred.

5.2 Crop removal rates

When grain is harvested from the paddock, nutrients (phosphorus, nitrogen, zinc, etc.) are removed in the grain. If, over time, more nutrients are removed than are replaced (via fertiliser) then the fertility of the paddock will fall.

Fertiliser inputs must be matched to expected yields and soil type. The higher the expected yield, the higher the fertiliser input, particularly for the major nutrients, phosphorus, potassium and sulfur.

A balance sheet approach to fertiliser inputs is a good starting point in considering the amount of fertiliser to apply to your pulse crop. Other factors such as soil type, paddock history, soil test and tissue analysis results, as well as your own experience all affect the choice of fertiliser to be used. Table 1 shows the amount of nutrients removed in each tonne of lupin seed. Nutrient budgeting is a simple way to calculate the balance between nutrient removal (via grain) and nutrient input (via fertiliser). [4]

Table 1: *Nutrient removal (kg) for each tonne of lupin seed.*

	Nitrogen	Phosphorus	Potassium	Sulfur	Calcium	Magnesium
Narrow-leafed lupin	51.2	3.0	8.0	2.3	2.2	1.6
Albus lupin	57.3	3.6	8.8	2.5	2.0	1.3

Source: Price (2006) in NSW DPI

3 GRDC (2013). Better fertiliser decisions for crop nutrition – Fact Sheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/11/grdc-fs-bfdcn

4 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

5.3 Soil testing

Key points:

- A range of soil test values used to determine if a nutrient is deficient or adequate is termed a critical range.
- Fertiliser decisions are in part based on where the soil test falls in relation to the critical range.
- Critical ranges for combinations of nutrient, crop and soil types are being established.
- Critical ranges have been established, and continue to be reviewed for topsoils (0 to 10 cm) and subsoils (10 to 30 cm in some cases, or to the depth of the crop root zone in others), depending on the nutrient.
- Deeper sampling is considered essential for understanding soil nutritional status and fertiliser requirement in northern cropping systems.

As all soils vary, it is important to conduct pre-sowing soil tests to work out application rates. In northern part of Northern cropping soils, nutrient deficiencies other than nitrogen (N) are a relatively recent development, whereas in the southern part of the Northern region, P has been an issue for some time. Consequently, there has been less nutrient research conducted in these soils and the many crop types grown in Northern cropping systems.

The importance of subsoil layers for nutrients such as P and K is not yet reflected in the limited soil test-crop response data available. Researchers are currently using rough rules of thumb to help interpret deep P and K soil tests in terms of likely fertiliser responsiveness on Northern region Vertosols.

Tests for N and S provide information on nutrient supply, while P and K tests indicate nutrient sufficiency. If critical nutrient ranges for soil and crop species are available, the soil test information can be used to support decisions about fertiliser rate, timing and placement.

Appropriate soil tests for measuring soil extractable or plant available nutrients in the Northern cropping region 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; and
- 2M KCl extractable mineral N, to provide measurement of nitrate-N and ammonium-N.

Other measurements that aid the interpretation of soil nutrient tests include:

- soil carbon/organic matter content;
- phosphorus buffering index (PBI);
- for micronutrients such as Zinc, Copper and Molybdenum;
- soil salinity measured as electrical conductivity; and
- chloride and other exchangeable cations including aluminium.

5.3.1 Collecting soil samples for nutrient testing

The greatest source of error in any soil testing service comes from collection of the soil. Soil sampling does not have a single, definable strategy. The strategy needs to be closely aligned to the reasons for testing. The most stringent sampling requirement occurs when the reason for sampling is predicting crop response to added fertiliser.

How many cores should be taken to represent an area? The general rule is that the more variable crop growth is in the field the more sub-samples are required to produce a meaningful paddock average. If the objective of soil sampling is monitoring trends in paddock fertility or problem solving, the number of cores representing an area can be substantially reduced.

To ensure that a sample is representative:

- check that the soil type and plant growth from where the sample is collected are typical of the whole area to be treated;
- avoid areas such as stock camps, old fence lines and headlands where nutrient concentrations are often significantly higher than the rest of the paddock;
- ensure that each sub-sample is taken to the full sampling depth;
- do not sample in very wet conditions;
- avoid shortcuts in sampling such as taking only one or two cores or a handful or a spadeful of soil, which will give misleading results; and
- avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers, other sources of nutrients or organic materials such as oils used to lubricate deep probes.

5.3.2 Sampling depth

The most common soil sampling depth for nutrient analysis is 0 to 10 centimetres for broadacre crops. This layer was chosen because nutrients, especially P, and plant roots are concentrated within this layer. To obtain more comprehensive soil data, including nutrient data, sampling below 10 cm should be considered for some nutrients.

Suggested sampling increments for key nutrients and salinity for northern cropping regions are:

- 0 to 10 cm (N, P, K and S);
- 10 to 30 cm (N, P, K and S);
- 30 to 60 cm (N, salinity and sodicity);
- 60 to 90 cm (N, S and salinity); and
- 90 to 120 cm (optional) (N, S and salinity).

Deeper sampling does raise issues of logistics and cost, which should be discussed with soil test providers. However, the additional information provides a clearer insight into nutrient status in the crop root zone.

5.3.3 Critical values and ranges

A soil test critical value is the soil test value required to achieve 90% of maximum potential crop yield, while the critical range reflects the degree of uncertainty around the critical value. The narrower the range, the more reliable the prediction of a fertiliser response from the available data.

The critical range determines if a nutrient is likely to be deficient for crops based on whether the soil test value is greater than or less than the upper or lower critical range value (Table 2).

Table 2: *Adequate levels for various soil test results.*

Phosphorus			
	Colwell	Olsen	
Sand	20–30	10–15	
Clay	25–35	12–17	
Loam	35–45	17–23	
Potassium			
	Bicarb	Skene	Exchangeable K
Sand	50	50	Not applicable
Other soils	100	100	0.25 me/100 g
Sandy loam (lupins)	30–40	-	-
Sulfur			
	KCl		
Low	5 ppm		
Adequate	8 ppm		

Source: Grain legume handbook

If the soil test value is less than the lower limit, the site is likely to respond to an application of the nutrient resulting in higher crop yields. For values within the range there is less certainty about whether a response will occur. Growers have to exercise judgement about the cost benefit of adding fertiliser in the coming season.

If the soil test is above the critical range, fertiliser may be applied to maintain existing soil levels or a controlled rundown of nutrient reserves can be conducted until fertiliser applications become viable.

Soil bulk density changes with texture and gravel content. As a rule, the bulk density of vertosols can range from 1.1 to 1.3 grams/cm^3.

The SoilMapp app provides details of soil bulk densities across Australia.

MORE INFORMATION

Soil testing for crop nutrition - Northern region Factsheet

Monitoring of soil phosphorus, potassium and sulfur to get the most out of your fertiliser dollar

5.4 Plant and/or tissue testing for nutrition levels

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

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

Several companies perform plant tissue analysis and derive very accurate analytical concentrations however it can be hard to interpret the results and determine a course of action. As with soil tests, different plants have different critical concentrations for a nutrient. In some cases, varieties can vary in their critical concentrations (Table 3). Care should be taken to use plant tissue tests for the purpose for which they have been developed. Most tests diagnose only the nutrient status of the plants at the time they are sampled and cannot reliably indicate the effect of a particular deficiency on grain yield. [5]

5 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/resources-and-publications/all-publications/publications/2008/03/2008-grains-legume-handbook

Table 3: *Critical nutrient levels for sweet lupins at flowering. Any nutrient level below the critical range will be deficient; any level above will be adequate.*

Nutrients	Plant part	Critical range
Phosphorus (%)	Youngest mature leaf	0.2
Potassium (%)	Youngest mature leaf	1.5
Sulfur (%)	Whole shoot	0.2–0.25
Magnesium (%)	Youngest mature leaf	0.17
Boron (mg/kg)	Youngest mature leaf	15
Copper (mg/kg)	Youngest mature leaf	3.0
Manganese (mg/kg)	Stem at primary bud stage	20
Zinc (mg/kg)	Youngest mature leaf	12–14

Source: Grain legume handbook

5.4.1 What plant-tissue analysis shows

Plant tissue analysis shows the nutrient status of plants at the time of sampling. This, in turn, shows whether soil nutrient supplies are adequate. In addition, plant tissue analysis will detect unseen deficiencies and may confirm visual symptoms of deficiencies. Toxic levels also may be detected.

Although usually used as a diagnostic tool for correction of future nutrient problems, plant tissue analysis from young plants will allow a corrective fertiliser application in the present season.

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

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

Sampling tips:

- Sample the correct plant part at the specified time or growth stage; i.e whole plant tops.
- Use clean plastic disposable gloves to sample to avoid contamination.
- Sample tissue (e.g. entire leaves) from vigorously growing plants unless otherwise specified in the sampling strategy.
- Take a sufficiently large sample (adhere to guidelines for each species provided).
- When troubleshooting, take separate samples from areas of good and poor growth.
- Where necessary, wash samples while fresh to remove dust and foliar sprays.
- After collection, keep samples cool.
- Refrigerate or dry if samples cannot be dispatched to the laboratory immediately for arrival before the weekend.
- Generally, sample in the morning while plants are actively transpiring.

Practices to avoid:

- sampling spoiled, damaged, dead or dying plant tissue
- sampling plants stressed by environmental conditions
- sampling plants affected by disease, insects or other organisms
- sampling soon after applying fertiliser to the soil or foliage

- contaminating samples with dust, fertilisers and chemical sprays or perspiration and sunscreen from hands
- sampling from atypical areas of the paddock, e.g. poorly drained areas
- sampling plants of different vigour, size and age
- combining samples from different cultivars (varieties) to make one sample
- placing samples into plastic bags, which will cause the sample to sweat and hasten its decomposition
- sampling in the heat of the day; i.e. when plants are moisture-stressed
- mixing leaves of different ages. [6]

5.5 Nitrogen

Key points:

- Lupins are legumes and fix their own nitrogen unless they are in soils with little to no compatible rhizobia.
- Nitrate (NO3–) is the highly mobile form of inorganic N in both the soil and the plant.
- Sandy soils in high-rainfall areas are most susceptible to nitrate loss through leaching.
- Lupin yield is generally more sensitive to early nitrogen deficiency than deficiency during flowering or seed-filling. If nitrogen deficiency (through poor nodulation) occurs early in plant growth, the plant is less likely to recover and there will be a greater delay in plant development.
- Soil testing and N models will help to determine seasonal N requirements.

In natural systems, amounts of soil organic N (humus, microbial biomass, plant residues and dung) tend to be stable, although they will vary according to soil type, rainfall, and air and soil temperatures, in turn affecting the landscape vegetation. Typical organic N levels in the NSW grainbelt soils may be 1 to 2 t/ha in the top 10 centimetres and 5 to 8 t/ha in the top 1m of soil. [7]

Symbiotic nitrogen fixation is the mutually beneficial relationship between the pulse (or any legume) host and Rhizobium bacteria. These bacteria colonise roots during seed germination then multiply rapidly to form root nodules within 4–10 weeks. They are dependent on the host plant for water, nutrients and energy, but in return supply the plant with nitrogen (ammonium, NH4+) for direct uptake. This 'fixed' nitrogen is derived from the enormous N_2 gas resources of the earth's atmosphere (around 80%) – the same source used by the Haber and Bosch process to manufacture compound N fertiliser.

Pulses (and pasture legumes) play an essential role in the nitrogen supply chain of field crops, especially since nitrogen is one of the most limited plant nutrients worldwide. Under good symbiotic associations with lentil, up to 87% of the total N in the crop may be derived from symbiotic N_2 fixation. By fixing their own nitrogen during growth, pulses become independent of soil mineral nitrogen and thereby conserve or spare it. When combined, these two sources (fixed and spared N) produce large amounts of residual nitrogen for following crops, boosting both their grain yield and grain protein. Compared to manufactured nitrogen fertiliser, biologically fixed nitrogen is:

- less volatile;
- more stable;
- 'slow release';
- environmentally sustainable;

6 SoilMate (2010) Guidelines for sampling plant tissue for annual cereal, oilseed and grain legume crops. Back Paddock Co., http://www.backpaddock.com.au/assets/Product-Information/Back-Paddock-Sampling-Plant-Tissue-Broadacre-V2.pdf?phpMyAdmin=c59206580c88b2776783fdb796fb36f3

7 D Herridge. (2013). Managing legume and fertiliser N for Northern grains cropping. https://www.researchgate.net/publication/293958450_Managing_Legume_and_Fertiliser_N_for_Northern_Grains_Cropping

- less energy demanding to manufacture;
- cost effective;
- not subject to supply restrictions or price fluctuations; and
- not subject to the challenges of application timing and utilisation efficiency. [8]

5.5.1 Nitrogen effects on lupin growth

It is uncommon for growers to apply nitrogen to a lupin crop as plants are able to fix their own nitrogen.

Nitrogen fixation stops with the onset of pod filling. Nitrogen is translocated from the stems, leaves and pods to the growing seed. Nitrogen deficiency early in pod filling reduces seed protein levels. Lupin yield is generally more sensitive to early nitrogen deficiency than deficiency during flowering or seed-filling.

If nitrogen deficiency (through poor nodulation) occurs early in plant growth, the plant is less likely to recover and there will be a greater delay in plant development. Nitrogen deficiency around the time of floral initiation can delay flowering. It reduces the number of leaves initiated and slows the rate of leaf appearance. This does not affect the time to floral initiation, but it can delay flowering. The delay can be between 68 and 220 degree-days (4 to 14 days), depending on the sowing date. Nitrogen deficiency also reduces flower numbers and slows branch growth. [9]

5.5.2 Nitrogen fixation benefits

Legumes (crop and pasture combined) are estimated to fix almost 3 million tonnes of nitrogen each year in Australia, which is worth around $4 billion. This amount of fixed N makes a substantial (around 50%) contribution to the estimated 6 million tonnes of nitrogen that are required annually for grain and animal production on Australian farms.

The contributions made by legumes vary considerably with the species (Table 3) and with the situation (soil type, seasonal rainfall and crop management). Nitrogen fixation generally increases with increased crop biomass, therefore good agronomic management leading to good legume growth will favour higher N inputs from fixed N. There are also significant contributions of fixed N from legume roots (Table 3). Legume growth is strongly influenced by the amount of water that the crop or pasture can access from the combination of stored soil moisture and growing season rainfall. Management practices that optimise Water Use Efficiency, and also keep soil nitrate levels low, will favour legume growth and N fixation. The fixed N is used by the legume itself for growth, but any root and shoot residues remaining after grain harvest or pasture grazing (for pastures legumes) will contribute to soil nitrate which can provide N to subsequent crops. [10]

Table 4: *Estimates of the amounts of N fixed annually by crop legumes in Australia.*

Legume	% of crop N requirement fixed	Shoot dry matter (t/ha)	Shoot N (kg/ha)	Root N (kg/ha)	Total crop N (kg/ha)	Total N fixed1(kg/ha)
Lupin	75	5.0	125	51	176	130

*Total N fixed = Percent N fixed x Total crop N; data sourced primarily from Unkovich et al. (2010

Source: GRDC

MORE INFORMATION

Legume effects on soil N dynamics - comparisons of crop response to legume and fertiliser N

CSIRO Soil Research paper: Mark Peoples

8 E Armstrong, D Holding. (2015). Pulses: putting life into the farming system. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/558958/Pulses-putting-life-into-the-farming-system.pdf

9 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

10 M Ryder, M Denton, R Ballard. (2014). GRDC Update Papers: Maximising the nitrogen (N) benefits of rhizobial inoculation. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Maximising-the-nitrogen-N-benefits-of-rhizobial-inoculation

5.5.3 Estimating fixed nitrogen

The amount of nitrogen fixed by a pulse is directly proportional to its growth, estimated at 20 to 25 kg N fixed per tonne of dry matter (DM) produced.

Total Fixed N (kg/ha) = Maximum DM (t/ha) x 25 (kg N/ t)

Maximum DM, hence maximum fixed N, occurs just prior to physiological maturity, when pods are almost filled and start to yellow. Farmers can ensure their pulse DM is maximised by adopting best management practices, especially inoculation, sowing time, establishment, weed control and disease management.

A simple tool growers can use to estimate DM of their pulse crop is to apply harvest index to their actual harvested grain yields. Harvest index (HI) is the percentage of grain in total above ground DM. Reported HI in pulses varies from 20–50%.

Maximum DM (t/ha) = [grain yield (t/ha) x 100] ÷ HI %

Growers need to interpret HI from visual assessment of how well their crop has grown during spring, taking into account management factors such as agronomy, weeds, pests, disease and environmental factors (e.g. frosting, lodging). Tall, bulky crops with poor pod set have low HI (less than 25%), while short well podded crops have high HI (greater than 40%). [11]

5.5.4 Estimating residual nitrogen

The best way to estimate residual nitrogen is to test soil late in the summer, using both deep and shallow tests.

The residual nitrogen benefit can be estimated by subtracting nitrogen exported in grain from estimates of nitrogen fixed (as described above).

Residual N (kg/ha) = total fixed N (kg/ha) – N removed in grain (kg/ha)

Estimates of residual nitrogen for lentil, field pea and faba bean are presented in Table 5.

11 E Armstrong, D Holding. (2015). Pulses: putting life into the farming system. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/558958/Pulses-putting-life-into-the-farming-system.pdf

Table 5: *Estimates of above-ground nitrogen fixed (kg/ha) by lupins based on harvest index (HI).*

Grain Yield (t/ha)	Narrow leafed lupin			Albus lupin		
	HI 20%	HI 30%	HI 40%	HI 20%	HI 30%	HI 40%
0.40	31	15	6	28	12	3
0.60	47	22	10	42	17	5
0.80	63	30	13	56	23	6
1.00	79	37	16	71	29	8
1.20	94	44	19	85	35	10
1.40	110	52	23	99	41	11
1.60	126	59	26	113	46	13
1.80	141	66	29	127	52	15
2.00	157	74	32	141	58	16
2.20	173	81	35	155	64	18
2.40	189	89	39	169	69	19
2.60	204	96	42	184	75	21
2.80	220	103	45	198	81	23
3.00	236	111	48	212	87	24
3.20	252	118	52	226	93	26
3.40	267	126	55	240	98	28
3.60	283	133	58	254	104	29
3.80	299	140	61	268	110	31
4.00	314	148	64	282	116	32

The figures in this table are based on harvest index (HI). Growers need to interpret HI from visual assessment. Tall, bulky crops with poor pod set have low HI (less than 25%); short well podded crops have high HI (greater than 40%). The figures presented in this table are a guide only and should be used as such. Fixed N estimates will always be subject to assumptions and variables beyond the grower's control. These fixed N estimates may not necessarily reflect differentials in soil nitrate levels at sowing of the following crop. N fixed will be optimised by growing the pulse best adapted to the environmental conditions using sound agronomic practices.

Source: NSW DPI

Assumptions:

- These estimates consider above ground biomass only. Approximately one third of total fixed N is found below ground.
- Estimates apply only to 'run-down' soils with low mineral N, forcing optimum efficiency of nitrogen fixation. Such soils occur late in the cropping cycle, the traditional position for pulses in the cropping sequence.
- Effective nodulation and optimum rhizobia numbers.
- Pulse DM becomes fully decomposed over time and available plant ammonia and nitrate is fully released by biological activity. Environmental conditions inevitably lead to losses from the system and affect the rate of decomposition.
- 25 kg N fixed per tonne DM.
- Grain protein of narrow leafed lupin = 29% and albus lupin = 34%
- Harvest index (HI) generally varies from 20 to 40%, but can be outside this range.

Fixed N will always be subject to assumptions and variables beyond the grower's control. Therefore, the calculations presented above are only estimates of potential N fixed. Grower and advisor experience is required to refine and make practical sense and application to their specific circumstances. Differences in fixed N estimated in the accompanying table may not necessarily reflect actual soil nitrate levels at sowing of the following crop.

In reality, the best assessment of the benefit of pulse fixed N is in the grain yield and protein response of the following crops, and in associated benefits to sustainability and profitability of the whole farming system.

Since substantial responses in cereals after all pulses are well known, tactically it is best for farmers to focus choice of pulse more on adaptation, performance, marketing and profitability of the pulse in their specific farming system rather than on potential to fix nitrogen. [12]

5.5.5 Nitrogen deficiency

Symptoms of nitrogen deficiency in lupin can be difficult to detect. The main method of identifying nitrogen deficiency is to assess the nodulation of lupin plants. For more information on assessing nodulation, see Section 3: Planting, section 3.1.4 Assessing nodulation.

On infertile soils, nitrogen deficiency can develop early in crop development, before enough nitrogen has been fixed. In some cases, using starter nitrogen can improve early plant vigour. Short periods of waterlogging can also reduce nodulation and cause nitrogen deficiency.

Nitrogen deficiency around the time of floral initiation can delay flowering. Nitrogen deficiency also reduces flower numbers and slows branch growth.

Lupin yield is generally more sensitive to early nitrogen deficiency than deficiency during flowering or seed-filling. [13]

IN FOCUS

Nitrogen deficiency slows leaf development and delays flowering in narrow-leafed lupin

Effects of nitrogen (N) supply on leaf and flower development in narrow-leaf lupin (cv Merrit) were examined in a temperature-controlled glasshouse. Low N supply (0.05 or 0.4 millimolar (mM) of N) had little effect on leaf initiation but slowed leaf emergence on the main stem compared with plants receiving high N supply (6.0 or 6.4 mM of N), or with symbiotic N_2-fixation. Plants experiencing transient N deficiency had slower leaf emergence than plants with a continuous supply of 6.4 mM of N. Nitrogen supply did not affect the time of floral initiation, which occurred within 4 weeks of sowing, by which time nine to ten leaves had emerged. However, the flowering of low-N plants was delayed by 68 to 220°C d (i.e. 4–14 d) even though they had fewer leaves. The effect of N deficiency on flowering time was largely a result of slower leaf emergence. [14]

MORE INFORMATION

Nitrogen deficiency slows leaf development and delays flowering in narrow-leafed lupin

5.5.6 Managing nitrogen

Key points:

- In some cases, using 'starter' nitrogen can improve early plant vigour in lupin.

12 E Armstrong, D Holding. (2015). Pulses: putting life into the farming system. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/558958/Pulses-putting-life-into-the-farming-system.pdf

13 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

14 Q Ma, N Longnecker, M Dracup (1997) Nitrogen deficiency slows leaf development and delays flowering in narrow-leafed lupin. *Annals of Botany*, *79*(4), 403–409.

- Applying 5 kg/ha of 'starter' nitrogen at sowing can assist lupin establishment. At this low rate lupin nodulation is not inhibited. Note this contains phosphorus so care must be taken to avoid toxicity if applied with seed.

High levels of nitrogen in the soil will inhibit nodulation and nitrogen fixation. Spreading nitrogen fertiliser may therefore reduce the amount of nitrogen fixed by the plant. Nevertheless, application of small amounts of nitrogen fertiliser at seeding is often recommended for pulse crops, particularly on acid soils (sometimes termed 'starter N' and applied at 5 to 10 kg N/ha). 'Starter' fertilisers such as MAP and DAP can be used on pulses. Some growers worry that using nitrogen on their pulse crop will affect nodulation. This amount of nitrogen fertiliser is too low to inhibit nodulation, but is sufficient to stimulate early seedling growth and crop establishment in situations where nodulation is delayed by soil acidity or low temperature. [15] A benefit from using the starter nitrogen is that early plant vigour is often enhanced and on low fertility soils, yield increases can be made. [16]

Soil testing for paddock nutrition prior to sowing is the best way to know whether crops may be at risk of nitrogen deficiency. For more information on soil testing, see Section 5.2 Soil testing, above.

NBudget

'NBudget' is simple-to-use Excel-based calculator designed to help farmers and their advisers in Australia's Northern grains region estimate soil nitrate and water levels at sowing and fertiliser N requirements for cereals and oilseeds. 'NBudget' also provides estimates of the amount of N fixed by the grain legume crops. 'NBudget' uses the established N budgeting approach in which estimates of N demand and N supply are compared in order to calculate fertiliser N requirements. A major difference between 'NBudget' and other calculators/tools for N management is that soil testing for either nitrate, organic carbon or water is not required. Rather, 'NBudget' contains rule-of-thumb values for soil nitrate based on paddock nutrient fertility status and recent paddock history and linked equations for calculating soil nitrate following crop growth and post-crop fallow. [17]

MORE INFORMATION

Managing legume and fertilser N for Northern grains cropping

5.6 Phosphorus

Key points:

- Phosphorus (P) reserves have been run down over several decades of cropping.
- Testing subsoil (10 to 30 cm) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Lupin has variable responses to P application. It is important for growers to note that P applied with seed can be potentially damaging by burning seed and reducing growth.
- Application rates on responsive soils should be similar to cereals to achieve optimum yields and maintain soil phosphorus (P) levels – usually 15–25 kg/ha.
- Applying P at depth (15 to 20 cm deep on 50 cm bands) can improve yields over a number of cropping seasons (if other nutrients are not limiting).

Reserves of mineral nutrients such as phosphorus (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). However, central and southern parts of the Northern region have been applying P for a longer period.

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15 P White, M Harries, M Seymour, P Burgess (2005) Producing pulses in the northern agricultural region. Department of Agriculture and Food, Western Australia, Perth. Bulletin 4656.

16 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

17 D Herridge (2011). Managing legume and fertiliser N for northern grains cropping. Grains Research & Development Corporation.

P is largely immobile in the soil, particularly in clay soils, so P applied to the topsoil (0 to 10 cm) layer will not penetrate into the subsoil. P is being removed from the deeper subsoil layers (10 to 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 to 40 cm to drought-proof cropping systems in northern parts of the Northern region, which have a greater reliance on stored soil moisture rather than in-crop rainfall. [18]

5.6.1 Phosphorus effects on lupin growth

Low phosphorus has a greater impact on reproductive development than vegetative growth of lupin. Phosphorus deficiency slows the rate of leaf appearance and delays flowering. It also reduces the number of flowers on the flower spike. High phosphorus increases the number of pods set and the yield on lateral branches but has no effect on the number of seeds per pod or on pod size. [19]

5.6.2 Phosphorus deficiency

Use of P fertiliser means acute deficiency in broadacre crops is rare, with the exception of very acidic and high PBI (phosphorus buffering index) soils, P deficiency is often transitory and compounded by dry soil with symptoms disappearing when topsoil re-wets following rainfall.

What to look for in the paddock

- Smaller later flowering plants with worse symptoms on higher P-fixing, water repellent and very acidic soils, and in very dry seasons (Photo 1).

18 GRDC. (2012). Crop Nutrition: Phosphorus management Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2012/11/grdc-fs-phosphorusmanagements

19 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 1: *The most common symptom is reduced growth.*

Source: DAFWA

What to look for in the plant

- Most common symptoms are smaller plants, narrower stems and petioles and fewer laterals (Photo 2).
- Petioles and leaflets are more upward-angled giving affected plants a more upright appearance.
- Growth is severely reduced before leaf symptoms show.
- As deficiency progresses older leaf leaflets turn muddy greyish-green and tend to droop (Photo 3).
- Severely deficient leaflets wither from the tip and die, often twisting, then drop-off, followed by the petioles (Photo 4). [20]

20 DAFWA (2015) Diagnosing phosphorus deficiency in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-narrow-leafed-lupins

Photo 2: *Smaller plant with thinner stems and fewer lateral branches.*

Source: DAFWA

Photo 3: *Older leaves on very deficient plants turn muddy grey-green and wither.*

Source: DAFWA

Photo 4: *Leaves on severely deficient plants bend or become twisted before dying.*

Source: DAFWA

5.6.3 Managing Phosphorus

Most soils where pulses are grown are deficient in available P. A 1 t/ha lupin crop needs 4.5 kg/ha P although the rate of P applied as fertiliser will need to be greater than this on soils where P is less available to the crop.

Drill phosphate at seeding. Banding of phosphate below the seed can increase yields on some soils, particularly those with high phosphorous retention.

Application rates on responsive soils should be similar to cereals to achieve optimum yields and maintain soil phosphorus (P) levels – usually 15–25 kg/ha.

Rates of 15 kg/ha (160 kg/ha of superphosphate or the equivalent in high analysis Fertiliser) are justified in most environments. Responses in albus lupins are often very low or negligible to these rates of applied P. Higher analysis phosphate Fertilisers generally contain little sulfur so should be avoided on soils where sulfur levels are critically low, or supplementary sulfur applied, e.g. with gypsum. [21]

Be careful when using higher rates of high-analysis fertilisers as lupin seed is sensitive to fertiliser burn. Wider rows and narrow tynes, which can concentrate the seed and fertiliser together in a narrow band, exacerbate the risk of fertiliser burn. Sowing into marginal moisture conditions can also increase this risk. Consider separating the seed and fertiliser by banding fertiliser below the seed where possible. [22]

Lupins, and in particular albus or broadleaf lupins have been well known to be sensitive to large amounts of fertiliser next to the seed.

Sowing high rates of P with lupins can reduce nodulation and crop establishment on acid soils when sowing with narrow points. Deep banding of the fertiliser will avoid this. It is not recommended for deep acid sands where P can leach below the root zone. [23]

For more information, see Section 2: Pre-planting, Section 2.3.5 Safe rates of fertilser at sowing.

Deep placement of phosphorus and potassium fertilisers are increasingly required in northern region cropping programs to address low subsoil reserves of these

21 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

22 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

23 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

nutrients. Apply P at depths of 15 to 20 cm and in bands 50 cm apart, or closer if possible. If the bands are any wider than 50 cm there will not be enough plant roots to reach the high P zones and meet crop demand. Applying P in bands 25 to 50 cm apart produces stronger yield responses than bands 100 cm apart. This has been shown consistently across soil types and crops.

Increasing the volume of enriched soil is more effective than just increasing P rates. The key is placing bands in different positions each cropping season. The strategy of lower rates applied more frequently will eventually enrich enough of the soil volume to overcome P limitations, due to the excellent residual value of deep-placed P.

It is important to consider soil pH (e.g. acidic soils in the Northern region) when applying P. An interaction between soil pH and phosphorus fertiliser is most likely when: there are no other major nutritional constraints to crop growth; and a large change (>0.5 pH units) has been made to subsurface pH by lime application. When these two criteria have been met, an interaction between soil pH and phosphorus fertiliser can lead to greater availability of soil phosphorus. [24]

Soil testing

It is important to assess the P status of the subsoil periodically in the north of the Northern Region. Test the 10 to 30 cm layer using BSES-P as well as Colwell-P soil tests. Take the opportunity to test for K at the same time. Such testing will build a more complete picture of a soil's fertility and the values from the deeper layers can be used to refine your fertiliser strategy. P and K fertility in the subsoil changes more slowly than in the top 10 cm, where starter fertiliser is applied and where nutrients are deposited via crop residues. Subsoil tests are an extra expense; however, they generally only need to be done once every four to six years. Analysing grain for nutrient content provides additional information when monitoring soil fertility by accounting for the amount of nutrient removed with each harvest.

Colwell-P

The Colwell-P test uses a bicarbonate (alkaline) extraction process to assess the level of readily available soil P. It was the original test for P response in wheat in northern New South Wales. It is used with the phosphorus buffering index (PBI) to indicate the sufficiency and accessibility of P in the soil.

BSES-P

The BSES-P test was developed for the sugar industry but is now an important tool in the grains industry. BSES-P uses a dilute acid extraction to assess the size of slower release soil P reserves. These reserves do not provide enough P within a season to meet yield requirements, but they partially replenish plant-available P. Because the P measured by BSES-P releases only slowly, changes in the test value of subsoil layers may take years. Therefore, this test needs to be done only every four to six years, and is most important in the subsoil layers.

PBI

The 'buffering capacity' of a soil refers to its ability to maintain P concentration in solution as the plant roots absorb the P. The phosphorus buffering index (PBI) indicates the availability of soil P. The higher the value, the more difficult it is for a plant to access P from the soil solution. Generally, a PBI value of less than 300 (a range that would include most northern vertosols) indicates that soil P, as assessed by Colwell-P, is readily available. Colwell-P and PBI values are needed in both 0 to 10 cm and 10 to 30 cm soil tests. BSES-P is optional in the 0 to 10 cm layer but essential in the 10 to 30 cm layer. [25]

MORE INFORMATION

Phosphorus management – Northern region

24 C Scanlan. (2016). GRDC Update papers: The interaction between soil pH and phosphorus fertiliser is dynamic. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/the-interaction-between-soil-ph-and-phosphorus-fertiliser-is-dynamic

25 GRDC. (2012). Crop Nutrition: Phosphorus management Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2012/11/grdc-fs-phosphorusmanagements

5.7 Sulfur

Sulfur is an essential plant nutrient required by all crops for optimum production. After N, P and K, Sulfur (S) as a secondary nutrient element appears to be most important, as S concentration in legumes is almost double that of cereals. Plants take up and use S in the sulfate (SO4-S) form, which like nitrate (NO3-N), is very mobile in the soil and is prone to leaching in wet soil conditions, particularly in sandy soils. Sulfur must be present for good nodule development on pulse crop roots.

In lupin, S is needed for seed production and to form chlorophyll and protein. It also helps in nodule formation and is essential for nitrogen fixation. Most soils in NSW have adequate levels of sulfur for lupin production. Research into S nutrition of lupins has been limited due to its lower requirement for S than other crops.

The key processes in the sulfur cycle in the Northern cropping soils are the reactions between soil solution sulphate and soil organic S, solution sulphate and adsorbed sulphate and loss of S by leaching. From a crop's point of view, the majority of the S it acquires early in the life cycle is most likely derived from immediate release of S from crop residues that remains in the surface soil, and mineralisation of S from organic matter over the fallow period.

MORE INFORMATION

Sulfur in Northern Vertosols

5.7.1 Sulfur deficiency

Deficiency can occur in wet seasons on deep sands, or where fertilisers low in S have been used for years. Sulfur is usually adequate on soils where gypsum has been applied in recent years. [26]

Sulfur deficiency occurs when growers use high analysis n and P fertilisers that are low in S and in wet growing seasons due to leaching of S.

If sulfur deficiency is suspected, then a tissue test is the best way to confirm the deficiency.

Leaf symptoms of sulfur deficiency are generally not distinct enough to be detected in the paddock. When sulfur is deficient, protein synthesis is inhibited and plants become pale, with symptoms similar to those of N deficiency in legumes. If sulfur deficiency is suspected, then a tissue test is the best way to confirm the deficiency. [27]

What to look for in the paddock

- Smaller paler plants (Photo 5).
- Deficiency is most likely in cold wet conditions on deep pale sands.

26 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

27 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 5: *Growth and colour are affected simultaneously.*

Source: DAFWA

What to look for in the plant

- Growth and colour are affected simultaneously.
- The whole plant becomes pale but middle leaves are affected last (Photo 6).
- New leaves and new growth become very pale green and clumpy due to increasingly miniature leaves with spiky-tipped leaflets (Photo 7).
- Older leaf leaflets drop, and have total or mottled chlorosis. [28]

Photo 6: *New leaves and new growth become very pale green and clumpy.*

Source: DAFWA

28 DAFWA (2015) Diagnosing sulfur deficiency in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-sulfur-deficiency-narrow-leafed-lupins

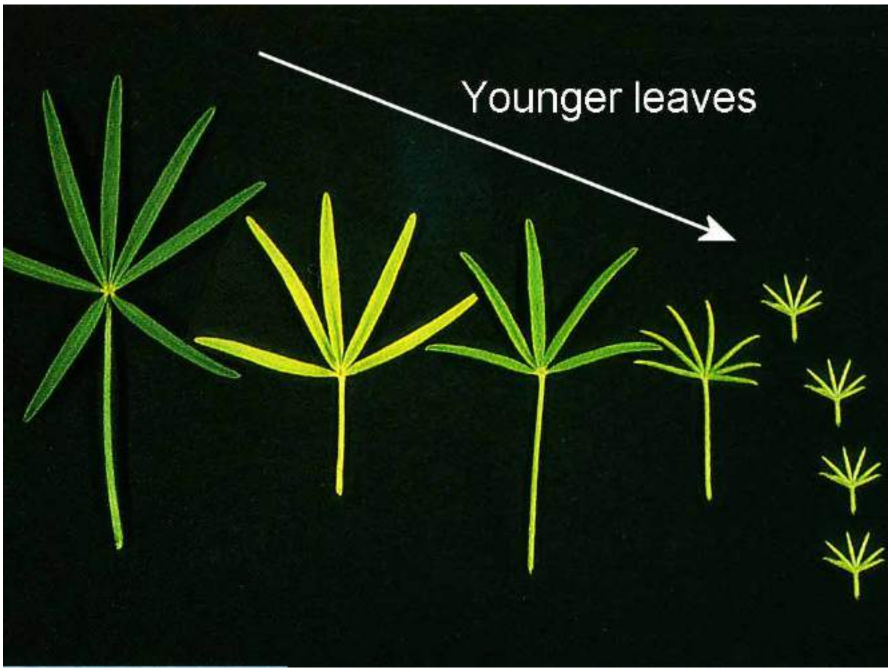


Photo 7: *Uniformly pale and increasingly miniature leaves with spiky-tipped leaflets.*

Source: DAFWA

5.7.2 Managing sulfur

Historically, S has been adequate for crop growth because S was supplied in superphosphate. It is recommended that growers use fertilisers blended with a sulfur component.

Sulfur management specific to lupins is often unnecessary as other crops require S before it becomes a problem in narrow-leafed lupins.

S soil levels are easily managed due to the high availability of S products when applied in soil systems as most soil types have a limited ability to form unavailable S complexes. Some management practices are inadvertently supplying significant amounts of S through the application of gypsum to manage sodicity, application of ammonium sulphate as a source of N and even a standard application rate of 100 kg/ha of MAP/DAP will supply approximately 1.5 kg S/ha. [29]

5.8 Potassium

Potassium (K) is required by all plant and animal life. Adequate potassium results in superior quality of the whole plant due to the improved efficiency of photosynthesis, increased resistance to some diseases and greater Water Use Efficiency. Potassium helps maintain a normal balance between carbohydrates and proteins.

K is used in many plant processes (e.g. photosynthesis, sugar transport and enzyme activation). It is particularly important in regulating leaf stomata. Plants that have adequate levels of potassium are better able to tolerate drought and waterlogging than plants deficient in potassium. Lupin takes up less potassium than wheat and canola but uses it more effectively. No potassium deficiency has been reported in lupin crops in NSW. [30]

Potassium deficiencies are most common on well drained, coarse-textured soils.

29 S Mason (2016) GRDC Update Papers: Monitoring of soil phosphorus, potassium and sulfur in the southern region – how to get the most out of your fertiliser dollar. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/monitoring-of-soil-phosphorus-potassium-and-sulfur

30 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

5.8.1 Potassium deficiency

Narrow-leafed lupins have a high potassium (K) requirement, but are able to access soil reserves at a greater depth than cereals.

Sandy, acid soils in high rainfall areas are most prone to potassium deficiency, particularly if cut for hay.

What to look for in the paddock

- Smaller paler plants that have lost older leaflets but retained the petioles.
- Symptoms are worse on lighter sands and often appear as patches of poor growth amongst patches of better growth, in patches (livestock manure), or lines (harvest rows) (Photo 8).

Photo 8: *Smaller, thinner plants can be seen within the paddock and are more susceptible to disease.*

Source: DAFWA

What to look for in the plant

- Plants are smaller and paler with thinner stems and fewer laterals.
- Older leaves are affected first, some or all leaflets turn chlorotic then drop-off.
- Middle and younger leaves on severely deficient plants can become twisted and claw shaped (Photo 9).
- Petioles remain intact.
- Plants are more susceptible to diseases and water stress. [31]

31 DAFWA (2015) Diagnosing potassium deficiency in narrow-leafed lupin. https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-narrow-leafed-lupins

Photo 9: *Twisted and claw shaped middle and younger leaves on severely deficient plants.*

Source: DAFWA

5.8.2 Managing Potassium

Key points:

- Top-dressed or banded K fertilisers will correct the deficiency.
- Excessive K fertiliser leaching can occur if applied earlier than four weeks after sowing on very sandy soils in high rainfall areas, because roots are insufficiently developed to capture all of the K.
- Potassium chloride can be toxic when drilled with the seed. [32]

If needed apply potassium within four weeks of sowing. Clay soils have adequate amounts of potassium (K) for plant growth. However, sandy soils can be deficient in K. Fertiliser K is only required when there is lower than 50–70 ppm of K in the soil. [33]

32 DAFWA (2015) Diagnosing potassium deficiency in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-narrow-leafed-lupins

33 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

K deficiencies can be corrected with potassium (potash) fertiliser (K20).

The right time and right place to give the best K response is at seeding rather than topdressing. Muriate of potash is a salt and can cause damage to sensitive seeds when place together in the sowing row. The amount of damage will depend on row width, seeding points, soil texture and moisture. Banding below the seed at planting has been shown to give much better results than topdressing or pre-spreading.

The right rate will need to be higher than replacement because K is relatively immobile. If the K buffering capacity is high, and the non-exchangeable K pool is strongly depleted, the competition between the soil and plant can mean minimum rates of 50 to 100 kg K/ha are needed to see responses. If using test-strips run out at seeding, use a high rate to see if K supply is adequate.

Another consequence of the low mobility, especially in alkaline soils, is that high rates can be used to cover two or three or even more crops. It is better to use higher rates less frequently than lower rates every year.

The right source is usually MOP, mainly because it is significantly cheaper than sulfate of potash, potassium nitrate or potassium magnesium sulfate (langbenite). All commercially available K fertilisers are imported, although there is one current development to exploit greensand deposits of glauconite in WA. Some growers are concerned about adding extra chloride, but the amounts added are of little agronomic or environmental significance in adding to salt loads. [34]

MORE INFORMATION

Do we need to revisit potassium?

5.9 Micronutrients

Key points:

- Micronutrient deficiencies are best determined by looking at the overall situation: region, soil type, season, crop and past fertiliser management.
- Soil type is useful in deducing the risk of micronutrient deficiencies.
- Tissue testing is the best way to accurately diagnose a suspected micronutrient deficiency.
- When tissue testing, sample the appropriate tissues at the right time. Plant nutrient status varies according to the plant's age, variety and weather conditions.
- The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small.
- When applying fertiliser to treat a suspected deficiency, leave a strip untreated. Either a visual response or tissue testing can allow you to confirm whether the micronutrient was limiting.
- Adequate trace element nutrition is just as important for vigorous and profitable crops and pastures as adequate major element (such as nitrogen or phosphorus) nutrition.

Micronutrients are essential for healthy plant growth. The key challenge is accurate identification of deficiencies and knowing your risk level. Unlike the macronutrients such as nitrogen (N), phosphorus (P), sulfur (S) and potassium (K) micronutrients are only needed in small quantities. Even so, they can limit production. The most likely limiting micronutrients to Australian cropping systems are boron (B), copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn). Iron (Fe) can be important, especially on strongly alkaline soils.

Traditionally, cultivation distributed these micronutrients through the topsoil but the introduction of no-till and one-pass seeding equipment has led to more limited physical distribution.

Many soils in Australia are deficient in trace elements in their native condition. Despite many decades of research into trace element management, crops can still

34 R Norton (2014) GRDC Update Papers: Do we need to revisit potassium? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Do-we-need-to-revisit-potassium

MORE INFORMATION

Crop nutrition - micronutrients

What's new with Zinc; Some critical reminders

be found to be deficient in one or more of these trace elements. Just because trace element deficiencies have not been prevalent in recent years, does not mean they will not return.

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

Micronutrient deficiencies can be tricky to diagnose and treat. By knowing your soil type, considering crop requirements and the season, and supporting this knowledge with diagnostic tools and strategies, effective management is possible. [35]

Of the micronutrient listed above, Zn deficiency is probably the most important because it occurs over the widest area, particularly in south eastern Australia.

5.9.1 Zinc

Key points:

- Low supply is typically associated with alkaline soils over a wide range of textures. The use of lime can reduce zinc availability.
- Lupins remove 30 kg of Zinc from the soil for every tonne of grain harvested.
- Critical soil test values (DTPA) are generally less than 0.5 mg/kg. However, taken alone, test values are not a reliable predictor of zinc response.
- Tissue tests help guide diagnosis, and critical tissue concentrations in the youngest expanded blade of wheat is <14 mg/kg. However, the response curve is very steep.
- Zinc supplements can be applied with fertiliser as zinc oxide, chelated zinc or zinc sulfate. The latter products are soluble and can also be used for foliar applications. Product efficacy varies with the time and placement of application.
- No single source is a 'silver bullet' to all situations. [36]

Zinc (Zn) is involved in the enzyme systems of plants. It is needed for protein synthesis, hormone production, carbohydrate metabolism and membrane stability. Zinc is taken up from the soil solution as water-soluble zinc. Zn deficiency can severely limit legume production and reduce cereal grain yields by up to 30%.

Lupin is less efficient than other winter crops at accessing zinc from the soil. Lupin is grown mainly on acid soils where zinc deficiency is rare. Zinc deficiency is more common in high-pH soils and those with high carbonate content. Albus lupin is more sensitive than narrow-leafed lupin to zinc deficiency.

Zinc deficiency

Zn deficiency has been identified on many soil types. Acid sandy soils, sandy duplex soils, red-brown earths, calcareous grey soils, and red heavy soils have all had either Zn responses confirmed or crops have been identified with Zn deficiency symptoms. Zn deficiency appears to be equally severe in both high and low rainfall areas.

Zinc is not mobile in the soil, so requires even distribution in the profile. It may be a severe problem in soils low in vesicular-arbuscular mycorrhiza (VAM). Deficiency is not common in alkaline soils, but may occur in leached sandy soils of low zinc, and in soils over fertilised with phosphate.

Leaf symptoms of zinc deficiency are generally not distinct enough to be detected in the paddock. Plants with mild zinc deficiency produce new leaves that are slightly paler than non-deficient plants. Severe zinc deficiency causes irregular, dark-brown blotches on the tips and margins of older leaves and the crown. It can also delay

35 GRDC. (2013). Crop nutrition Fact Sheet. Micronutrients. www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients

36 R Norton (2014) GRDC Update Papers: What's new with zinc; maybe just some critical reminders? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Whats-new-with-zinc-maybe-just-some-critical-reminders

flowering. Other symptoms are a reduction in stem length and increased branching of lateral roots. [37]

What to look for in the paddock

- Young shoots are pale and bunched (Narrow leaf).
- Brown spots along the midrib (Narrow leaf).
- Youngest leaves yellow but veins remain green, edges turn red (Albus).
- Leaves are rosetted or umbrella-like.

Photo 10: *Plants can show pale new leaves bunched together.*

Source: DAFWA

What to look for in the plant

- Markedly pale new leaves with shortened petioles, causing a bunchy appearance.
- Leaflets of pale new leaves develop brown spots along their midribs (Photo 11).
- Leaflets become bent and curled, often backwards towards the petiole (Photo 12).
- Plants recover as they approach flowering. [38]

37 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

38 DAFWA (2015) Diagnosing zinc deficiency in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-narrow-leafed-lupins

Photo 11: *Leaflets develop brown spots along the midrib.*

Source: DAFWA

Photo 12: *Leaflets become bent and curled, often backwards towards the petiole.*

Source: DAFWA

Managing Zinc

Key points:

- Foliar spray (effective only in current season) or soil fertiliser drilled with the following crop.

- Zinc foliar sprays need to be applied as soon as deficiency is detected to avoid irreversible damage.
- As zinc is immobile in the soil, topdressing is ineffective, as it would only be available to the plant when the topsoil is wet.
- Zinc drilled deep increases the chances of roots being able to obtain enough in dry seasons.
- Zinc has a 15 to 20 year residual life in soil.
- Zinc present in compound fertilisers often meets the current requirements of the crop. [39]

Correction of Zn deficiency in a way which provides benefits after the year of treatment is possible through the use of Zn-enriched fertilisers or a pre-sowing spray of Zn onto the soil (incorporated with subsequent cultivations).

Apply zinc fertilisers as soil dressings of zinc chelates, sulfates or oxides two to three months before sowing the crop. As pulses are more responsive to zinc than cereals the addition of 2 kg/ha Zn in Fertiliser in the lupin year makes a sensible routine. [40]

The following mixtures are NOT compatible with peat, liquid and freeze-dried inoculants:

- chemicals containing high levels of zinc, copper or mercury
- fertilisers and seed dressings containing sodium molybdate, zinc and manganese

Zinc foliar fertiliser can alleviate deficiencies in the growing crop providing two applications are applied within four weeks to six weeks of emergence. [41]

Another option that will also provide long term benefits but has become available only recently is the application of fluid zinc at seeding. The advantage of this approach is that it will provide residual benefits for subsequent crops and pastures and has a low up-front application cost.

Only Zn-enriched fertilisers of the homogenous type (fertiliser manufactured so that all granules contain some Zn) are effective at correcting Zn deficiency in the first year of application. Short intervals between repeat applications of Zn will be necessary on heavy and calcareous soils in the high rainfall areas, while seven to ten year intervals will be acceptable in the low rainfall areas. Following an initial soil application of 2 kg Zn /ha repeat applications of 1 kg/ha will probably be sufficient to avoid the reappearance of Zn deficiency in crops and pastures. Most zinc-enriched fertilisers are now not sold as pure homogeneous types, but providing a homogeneous fertiliser is used as part of the mix then the final product is still satisfactory for correcting Zn deficiency.

Zinc can be mixed with many herbicides and pesticides but not all, so check with your supplier for compatible tank mixes before you make the brew. [42]

5.9.2 Manganese

The availability of Mn in soil is strongly related to soil pH. Soils with higher pH have lower Mn availability than soils with lower pH. Mn deficiency is therefore more likely to be a problem on alkaline soils. However, responses to Mn have also been recorded on impoverished, acid to neutral sandy soils.

The availability of Mn is also strongly affected by seasonal conditions and the availability is lowest during a dry spring. Transient Mn deficiency may also appear

MORE INFORMATION

What's new with zinc – some critical reminders

GRDC Paper: Maximising the nitrogen benefits of rhizobial inoculation

39 DAFWA (2015) Diagnosing zinc deficiency in narrow-leaf lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-narrow-leafed-lupins

40 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

41 GRDC (2017) Winter crop nutrition: Ute Guide – Lupin. http://uteguides.net.au/UteGuides/Details/a2a14721-8310–4091-bb49-b1a01ef29162

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

during cold, wet conditions but affected plants are often seen to recover following rains in spring when soil temperatures are high. [43]

Manganese (Mn) is needed for many metabolic processes in the plant, including chlorophyll production. It is relatively immobile in the plant. Lupins rarely suffer from manganese deficiency before flowering but have a strong demand for this nutrient as seeds develop and mature.

The vegetative phase is usually not affected, as deficiency symptoms occur mostly during pod fill.

Seed yields of lupin can be substantially reduced by manganese deficiency. Narrow-leafed lupin has a poor ability to accumulate manganese in its seed. The resulting deficiency can cause the seed to split. [44] Severe deficiency results in shriveled seeds, delayed maturity and crop failure.

Manganese deficiency

Manganese deficiency delays plant maturity, which is a condition most marked in lupins. Mn-deficient patches in lupins will continue to remain green months after the rest of the paddock is ready for harvest. Delayed maturity in patches of the crop is frequently the only visual symptom of Mn deficiency in lupins. Manganese deficiency usually has little effect on vegetative growth but can substantially reduce grain yield ('split seed', Photo 13). Leaves rarely show symptoms but in extreme cases unopened new leaves are pale green with small dead spots on the tips of the leaflets.

Photo 13: *Seeds split through the seed coat and may be shriveled.*

Source: DAFWA

What to look for in the paddock

- Lower yielding plants that stay green longer, and have straggly growth (Photo 14).
- Affected plants are more common in deep sandy parts of the paddock.

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

44 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

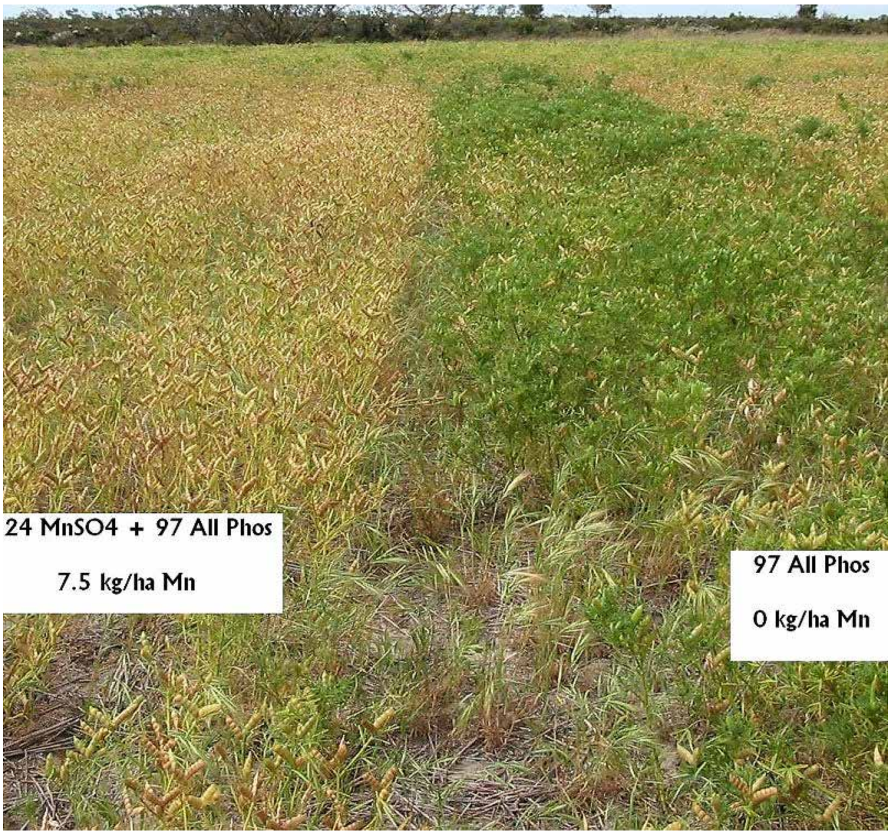


Photo 14: *Plants remain green but have straggly growth as leaves drop and pods fill on unaffected plants.*

Source: DAFWA

What to look for in the plant

- Plants stay green with straggly new growth as leaves drop and pods fill on unaffected plants.
- Seeds split through the seed coat and sometimes discolour around the margins.
- The seed may also be small, shrivelled and poorly developed.
- Young leaf leaflets develop a chlorotic margin with a dirty brown patchiness, but remain green near the base (Photo 15).
- Rarely, leaflets on severely deficient plants become claw shaped with purplish tips and margins. [45]

45 DAFWA (2015) Diagnosing manganese deficiency in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-narrow-leafed-lupins

Photo 15: *Young leaf leaflets develop a chlorotic margin with brown patches, but remain green near the base.*

Source: DAFWA

Managing Manganese

Key points:

- A foliar spray at pod size 2–3 cm on the main stem can prevent split seed but has almost no residual value.
- 25 to 30 kg manganese sulphate drilled at seeding is effective on yellow sands. Two applications will provide protection for at least 13–15 years.
- 15 to 20 kg manganese sulphate drilled before seeding is effective on white sands and sandy gravels. Two applications will provide protection for about 13 years.
- Manganese is immobile in the soil. Compared to drilled fertiliser, topdressed manganese is between 25%- 50% less effective, and deep placed manganese up to twice as effective in dry spring weather. [46]

46 DAFWA (2015) Diagnosing manganese deficiency in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-narrow-leafed-lupins

A tissue test value of less than 20 mg/kg in the top 10 cm of stem taken just before the first flower bud opens indicates 1.0 kg/ha of Mn should be applied as a foliar spray when the primary (first) flowering stems have small pods. [47]

Apply foliar sprays or soil dressing of manganese fertilisers such as manganese sulfate and oxides to control deficiency. Annual treatment with foliar manganese is probably more effective than at-sowing application. Manganese seed treatments are insufficient to meet plant requirements for the current season.

The following mixtures are NOT compatible with peat, liquid and freeze-dried inoculants:

- chemicals containing high levels of zinc, copper or mercury
- fertilisers and seed dressings containing sodium molybdate, zinc and manganese

Due to the detrimental effect of high soil pH on Mn availability, correction of severe Mn deficiency on highly calcareous soils can require the use of Mn-enriched fertilisers banded with the seed (3–5 kg Mn/ha) as well as 1–2 follow up foliar sprays (1.1 kg Mn/ha). In the current economic climate growers on Mn-deficient country have tended not to use Mn-enriched fertilisers (due to their cost) but have relied solely on a foliar spray. This is probably not the best or most reliable strategy for long term management of the problem.

The use of acid fertilisers (e.g. nitrogen in the ammonium form) may also partially correct Mn deficiency on highly alkaline soils but will not overcome a severe deficiency.

Mn deficiency in crops can also be corrected by fluid application at seeding. [48]

5.9.3 Manganese toxicity

Manganese toxicity is a more common issue in lupins than Mn deficiency. Manganese toxicity can develop on strongly acid soils, or in waterlogged soils that have more manganous ions available for plant uptake.

Symptoms

- Manganese toxicity develops first on the new leaves.
- Plants are stunted.
- Brown necrotic spots.
- Pale chlorotic areas.

Management

- Apply lime to acid soils to raise pH above 5.5.
- Improve drainage and avoid over fertilising with manganese fertilisers.
- Applying irrigation water low in manganese, or mulching with organic materials can remove soluble manganese from the soil solution and decrease the toxicity. [49]

5.9.4 Iron

Iron (Fe) is needed for effective nitrogen fixation, so the nodule initiation phase is the most sensitive to low soil iron levels. Plants with iron deficiency produce bright yellow young leaves. Iron deficiency is rare on acid soils. Narrow-leafed lupin is more sensitive than albus lupin to iron deficiency, especially on alkaline and calcareous soils. Waterlogged alkaline soils can also induce a temporary deficiency that dissipates when the soil dries out.

47 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

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

49 GRDC (2017) Winter Crop Nutrition Ute guide. http://uteguides.net.au/UteGuides/Details/a2a14721-8310-4091-bb49-b1a01ef29162

Iron deficiency

Lupin crops grown on fine-textured, alkaline soils that become saturated with water in winter will usually show bright yellowing of young leaves that is typical of iron deficiency.

What to look for in the paddock

- Smaller paler plants with chlorotic new leaves (Photo 16).
- Deficiency is most likely in deep pale or limed sands, and in waterlogged areas.

Photo 16: *In the paddock growers may notice paler plants with chlorotic leaves as a sign of iron deficiency.*

Source: DAFWA

What to look for in the plant

- Young leaves and new growth become yellow over the whole leaf (Photo 17).
- As deficiency often occurs in wet conditions, brown leaf spot lesions on leaves may also be present.

- Middle leaves of severely deficient plants may shrivel back towards the base of the leaflet. [50]

Photo 17: *Deficient leaves are uniformly pale. New growth is most affected.*

Source: DAFWA

Managing Iron

There are a complex series of interactions in the soil that combine to reduce the availability of iron to lupins. The deficiency will usually occur in lupin grown on soils with a pH above 7.0 if the soil aeration is reduced slightly and temperatures are cold.

Apply fertiliser as ferrous iron in foliar sprays or chelated iron in both soil and foliar spray. Foliar sprays need to be applied every 10 to 15 days to provide iron to the new leaves. Iron deficiency can impact on rhizobia fixing nitrogen and can induce nitrogen deficiency.

No yield responses to iron have been measured in the field to justify soil application. Foliar sprays will remove the symptoms where they occur in highly calcareous or limed soils

50 DAFWA (2015) Diagnosing iron deficiency in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-narrow-leafed-lupins

MORE INFORMATION

Molybdenum deficiency in plants

Where symptoms occur, particularly in cold and wet conditions, they are frequently eliminated by increased soil and air temperatures. [51]

5.9.5 Molybdenum

Molybdenum (Mo) is a constituent of the enzyme nitrate reductase, which converts nitrate-nitrogen (the form taken up from the soil) to nitrite-nitrogen (the form used by plants. It is also essential for nitrogen fixation. [52]

Use youngest fully-emerged leaf to test for molybdenum. Levels less than 0.005 mg/kg indicate deficiency. Take paired good/poor plant samples when possible. Unfortunately, there is no reliable soil test for molybdenum deficiency.

Molybdenum deficiency

In lupins, molybdenum deficiency results in paling because of nitrogen fixing problems and can also cause reduced growth and delayed flowering (Photo 18). [53]

Photo 18: *Molybdenum deficient (left) and molybdenum sufficient (right) narrow-leafed lupins.*

Source: Grain Legume Handbook

Managing Molybdenum

In most soils, molybdenum present in an unavailable form will be released by applying lime or dolomite. The effect of liming on molybdenum availability is slow and it may take several months to correct the deficiency. The amounts of lime or dolomite needed may range from 2 to 8 tonnes per hectare, depending on initial pH of the

51 DAFWA (2015) Diagnosing iron deficiency in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-narrow-leafed-lupins

52 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

53 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/resources-and-publications/all-publications/publications/2008/03/2008-grains-legume-handbook

soil and whether it is sandy or heavy textured. Unless lime is likely to be beneficial for other reasons, it is quicker and cheaper to apply a molybdenum compound to the soil or to the crop.

Where one of the molybdenum compounds is used, the quantities recommended vary from 75 g to 1 kg/ ha depending on the crop and the molybdenum material.

Molybdenum can be applied in the following ways:

- mixed with fertiliser; or
- in solution, to;
- seedlings in the seedbed before transplanting;
- the leaves of plants in the field; or
- the soil at the base of plants in the field. [54]

5.9.6 Cobalt

Rhizobia require Cobalt (Co) for effective nodule function, but it is not a plant nutrient. Cobalt is needed by the rhizobial bacteria to fix nitrogen. Therefore, Co deficiency reduces the nitrogen concentrations in the shoots. Narrow-leafed lupin is more sensitive than albus lupin to cobalt deficiency, especially on light textured soils. The cobalt level in lupin seeds needs to exceed 0.13 mg/kg to ensure that cobalt deficiency does not affect the rhizobia.

Symptoms of Co deficiency may only be seen in the form of reduced nodulation in lupin roots. [55]

Unfortunately, there is no reliable soil test for cobalt deficiency.

5.9.7 Boron toxicity

Boron toxicity occurs mostly on alkaline soils, which are less common in the Northern region. The most characteristic symptom of boron toxicity in pulses is chlorosis, and some necrosis if severe, at the tips or margins of the leaves. The older leaves are usually more affected. Lupin is not tolerant to highly alkaline soils so is not often grown in areas where boron toxicity occurs. However, lupin is sensitive to the effects of boron toxicity so growers should be aware of the symptoms described and ensure to conduct regular soil testing.

54 R Weir (2004) AGFacts: Molybdenum deficiency in plants. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/166399/molybdenum.pdf

55 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Weed control

Key messages

- Lupin has been ranked as one of the poorest pulse competitors against weeds.
- Altering sowing time and plant density can improve lupins' ability to compete with weeds.
- Increasing herbicide resistance in problems weeds in the Northern cropping regions means that growers should use Integrated Weed Management practices.
- Lupins provide unique opportunities for implementing weed control tactics as part of an integrated weed management plan, particularly for the control of herbicide resistant wild radish and annual ryegrass. A combination of crop-topping followed by harvest weed seed control can significantly reduce the weed seed bank.
- Lupin is sensitive to Group B, Group C and Group I herbicide damage.
- Ensure to spray under good conditions and to always keep good paddock records to avoid potential herbicide damage to own paddocks and neighbouring crops.
- Monitor crops for herbicide damage and keep an eye out for potentially resistant weeds (which should then be tested).

The total cost of weeds (revenue loss plus expenditure) to Australian grain growers is estimated at $3,318 million. Weed management has emerged as the major agronomic concern for most lupin growers with herbicide costs typically accounting for 40–50% of the variable cost of lupin production.

Effective weed control is essential for good yields and to avoid the buildup of troublesome weeds in the rotation. Plan your weed control strategy before sowing.

Herbicides applied pre-sowing or post-sowing pre-emergent (PSPE), or a combination of both, can control many broadleaf weeds. Most grass weeds can be controlled either pre-emergent or post-emergent, with the exception of those with herbicide resistance.

6.1.1 Lupin weed control summary

Effective weed control is critical to profitable lupin production. The widespread practice of dry sowing lupins with acceptable results in the 1980s has now compounded the weed control problem, through the missed opportunity for a mechanical and chemical pre-emergent knockdown and the often sub-optimal performance from simazine. Weed control has become particularly difficult where lupins have been grown on less suitable soil types. Under these circumstances the crop grows less vigorously and competes poorly with weeds.

Lupin has been ranked as one of the poorest winter crop competitors against annual ryegrass weeds, [1] however, increasing lupin plant density has been found to increase its competitive ability. [2] Because lupins are such poor competitors, they are more dependent on chemicals for weed control; which are not always available now that herbicide resistance in annual ryegrass is widespread.

Early trials over two seasons in Wagga Wagga (1996) explored the competitive ability of narrow-leaf and albus lupin against annual ryegrass weed. Cultivars of albus lupin tended to be more competitive than narrow-leaf lupin. The potential of lupins to compete with annual ryegrass was influenced by seasonal conditions. Early, vigorous

1 D Lemerle, B Verbeek, N Coombes (1995). Losses in grain yield of winter crops from Lolium rigidum competition depend on cultivar and season. Weed Research 35, 503–9.

2 J Allen(1977). Weeds in grain lupins. 1. The effect of weeds on grain lupin yields. Australian Journal of Experimental Agriculture and Animal Husbandry 17, 112–6.

growth and large leaf area are likely to give albus lupin cultivars a competitive advantage. [3]

The need to sow lupins early, their slow early growth coupled with the use of no till or reduced tillage techniques increases the dependence on herbicides for weed control.

There is a range of herbicides to control both broadleaf and grass/cereal weeds in lupins. Sowing early with successful crop establishment is essential to achieve more effective results from herbicides. [4]

An ideal weed control strategy for lupin involves:

- Plan rotations in advance to minimise weed challenge.
- Control weeds before or at sowing using physical, cultural and chemical methods.
- Maximise the effectiveness of the pre-emergent herbicide simazine by incorporating in wet soil.
- Ensure sowing depth is even so all plants are at the correct growth stage when post-emergent herbicides are applied.
- Spray small weeds early for an effective kill.
- Crop top with paraquat (Gramoxone) to reduce weed seed set at maturity.
- Implement harvest weed seed control. [5]

Ensure to uphold and consult paddock records, as lupin is sensitive to a number of herbicides.
For more information on herbicide damage in lupin, see Section 6.9 Potential herbicide damage effect.

6.2 Integrated weed management

Weeds present one of the largest costs to grain growers and are one of the biggest influences on the management of cropping systems. Their impact is multifaceted; they affect yield and management across all seasons, and sometimes crop price. In addition, the weed challenge faced by growers is constantly evolving, with changes in weed types and their characteristics, such as herbicide resistance, requiring the ongoing adaptation of management.

The Grains Research and Development Corporation (GRDC) supports integrated weed management. Download the Integrated Weed Management Manual.

Integrated weed management (IWM) is a system for managing weeds over the long term, particularly the management and minimisation of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given that there are additional costs associated with implementing IWM, the main issues for growers are whether it is cost-effective to adopt the system and whether the benefits are likely to be long-term or short-term in nature.

The manual looks at these issues and breaks it down into seven clear sections, assisting the reader to make the development of an integrated weed management (IWM) plan a simple process.

Successful weed management requires a field by field approach. Knowledge of weeds and weedbank status, soil types as relevant to herbicide use as well as cropping and pasture plans are all critical parts of the picture. Knowledge of paddock history and how much summer and winter weeds have been subjected to selection to resistance (and to which herbicide modes of action) can also assist.

MORE INFORMATION

Weed management as a key driver of crop agronomy

3 B Verbeek, D Lemerle (1996). Improving lupin competitive ability against annual ryegrass. In *Proceedings of the 11th Australian Weeds Conference, Melbourne, Australia, 30 September-3 October 1996* (pp. 122–123). Weed Science Society of Victoria Inc..

4 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

5 GRDC. Lupin weed control. https://grdc.com.au/archive/key-issues/lupin-weed-control/details

When resistance has been identified, knowledge of which herbicides still work becomes critically valuable information.

The following 5-point plan will assist in developing a management plan in each and every paddock.

1. Review past actions and history
2. Assess current weed status
3. Identify weed management opportunities
4. Match opportunities and weeds with suitably effective management tactics
5. Combine ideas into a management plan. Use of a rotational plan can assist [6]

An integrated weed management plan should be developed for each paddock or management zone.

In an IWM plan, each target weed is attacked using tactics from several tactic groups (see links below). Each tactic provides a key opportunity for weed control and is dependent on the management objectives and the target weed's stage of growth. Integrating tactic groups reduces weed numbers, stops replenishment of the seedbank and minimises the risk of developing herbicide-resistant weeds.

IWM tactics

- Reduce weed seed numbers in the soil
- Controlling small weeds
- Stop weed seed set
- Reduce weed seed numbers in the soil
- Hygiene - prevent weed seed introduction
- Agronomic practices and crop competition

Successful weed management also relies on the implementation of the best agronomic practices to optimise crop growth. Basic agronomy and fine-tuning of the crop system are the important steps towards weed management. [7]

There are several practices that improve crop competition against weeds, including reduced row spacing, higher sowing rates, east-west sowing direction and competitive cultivars.

6.2.1 Monitoring weeds

Record the key broadleafed and grass weed species for summer and winter and include an assessment of weed density, with notes on weed distribution across the paddock (Photo 1). 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.

6 GRDC. Integrated weed management hub. https://grdc.com.au/Resources/IWMhub

7 DAFWA. (2016). Crop weeds: Integrated Weed Management (IWM). https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm

Photo 1: *Scout for weeds throughout the year so that control can be applied at the optimal times.*

Source: Take Action

6.2.2 IWM in the Northern region

Broad-scale herbicide resistance is continuing to spread through the GRDC Northern Region. Growers can choose from a range of chemical and non-chemical integrated weed management tactics that delay or prevent resistance developing or control herbicide resistant weeds.

Major weeds of the northern grains region include feathertop rhodes grass, windmill grass, flaxleaf fleabane, wild radish, awnless barnyard and liverseed grasses, common sowthistle, wild oats and annual ryegrass.

Weeds cause economic losses in various ways, usually by reducing crop yields or contaminating harvested grain. Weeds use soil moisture during a fallow or cropping period, resulting in less moisture being available for the following crop.

Weed competition for moisture may result in poor crop establishment and growth, therefore reducing crop yield potential. For example, lupin seedlings are poor competitors and even relatively low densities of Group A-resistant wild oats in lupins can reduce yields significantly.

Weed seed contamination of harvested grain can result in either seed grading being required or discounts on contaminated grain.

Tactic Group 1 – Deplete weed seed in the soil seedbank

Burning residues, insect predation, inversion ploughing, autumn tickle, delayed sowing.

Tactic Group 2 – Kill weeds (seedlings)

Fallow cultivation, herbicides (knockdown, double-knock, pre-emergent, post-emergent), wide rows (band spraying, inter-row cultivation), spot spraying, wick wipers, chipping, weed detector spraying, biological control.

Tactic Group 3 – Stop weed seed set

In-crop weed management (spray-topping, crop-topping, wick wipers, desiccation and windrowing), pasture spray topping, silage and hay, manuring, mulching, hay freezing, grazing.

Tactic Group 4 – Prevent viable weed seeds being added to the soil seedbank

Weed seed control at harvest (narrow windrow burning, chaff cart, bale direct), grazing residues.

Tactic Group 5 – On-farm hygiene

Sow weed-free seed, manage weeds in non-crop areas, clean machinery, livestock movement, monitoring following flood events. [8]

MORE INFORMATION

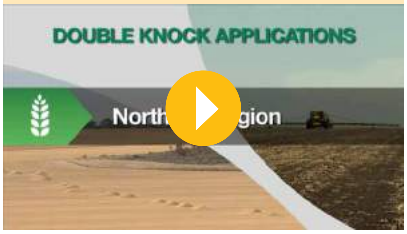
GRDC Integrated Weed Management hub

8 F Scott, T Cook. (2016). Costs of key integrated weed management tactics in the Northern region. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/678997/Costs-of-key-iwm-tactics-in-the-northern-region.pdf

VIDEOS

WATCH: Double knock application – a Grower's Experience.

WATCH: IWM: Double knock – Northern region



MORE INFORMATION

Costs of key Integrated Weed Management tactics in the Northern region

6.2.3 Double knock

A double knock approach is where two weed control tactics with different modes of action are applied within a period of usually four to 14 days to a single flush of weeds to control survivors from the first application, thereby stopping seed set. The second tactic, or knock, may also include cultivation, heavy grazing or burning as an alternative to a herbicide. This tactic is commonly used in fallow situations, but could be used in-crop.

The most common double knock approach is to apply a systemic herbicide (for example, Groups A, I or M) when conditions are favourable for maximum translocation, followed by a contact herbicide (for example, Group L). The intervals for maximum effectiveness will depend on the type of herbicide used, weed species being targeted, the size and age of weeds, temperature and moisture conditions. Higher water rates are often used for the second knock (100 L/ha). Double knock is more expensive than a single herbicide application and may not need to be applied every year. Conduct a paddock herbicide resistance risk assessment first.

Advantages:

- Minimises seed set.
- Delays the development of glyphosate and other mode of action herbicide resistance.
- Reduces the number of glyphosate resistant weeds to be controlled in-crop.
- May improve pre-sowing weed control, very useful for minimum or zero tillage systems.

Practicalities:

- Translocated herbicide should be applied first, followed by paraquat or a paraquat and diquat mixture.
- Time between applications will vary with the main target weed species.
- Identify the weed species being targeted to determine the most cost-effective chemistry. [9]

6.2.4 Herbicides explained

When selecting a herbicide, it is important to know crop growth stage, weeds present and plant-back period. For best results, spray weeds while they are small and actively growing. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur. Check product labels for up-to-date registrations and application methods.

Residual and non-residual

Residual herbicides remain active in the soil for an extended period (months) and can act on successive weed germinations. Residual herbicides must be absorbed through the roots or shoots, or both. Examples of residual herbicides include imazapyr, chlorsulfuron, atrazine and simazine.

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. Persistence of herbicides will affect the enterprise's sequence (a rotation of crops). Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and they are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

9 F Scott, T Cook. (2016). Costs of key integrated weed management tactics in the Northern region. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/678997/Costs-of-key-iwm-tactics-in-the-northern-region.pdf

VIDEOS

WATCH: Over the Fence North: Weed and nutrient research delivers at Silverton.

WATCH: GCTV17: Herbicide partnership.

Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, while pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. [10]

Herbicides have been classified into a number of 'groups'. The group refers to the way a chemical works – their different chemical make-up and mode of action (Table 1). [11]

Table 1: *Herbicide groups and examples of chemical products in each group.*

Group A	Hoegrass®, Nugrass®, Digrass®, Verdict®, Targa®, Fusilade®, Puma S®, Tristar®, Correct®, Sertin® Grasp®, Select®, Achieve®, Gallant®, Topik®
Group B	Glean®, Chlorsulfuron, Siege®, Tackle®, Ally®, Associate®, Logran®, Nugran®, Amber Post® Londax®, Spinnaker®, Broadstrike®, Eclipse®, Renovate®
Group C	Simazine, Atrazine, Bladex®, Igran®, Metribuzin, Diuron, Linuron, Tribunil®, Bromoxynil, Jaguar®, Tough®
Group D	Trifluralin, Stomp®, Yield®, Surflan®
Group E	Avadex®, BW, EPTC, Chlorpropham
Group F	Brodal®, Tigrex®, Jaguar®
Group H	Saturn®
Group I	2,4-D, MCPA, 2,4-DB, Dicamba, Tordon®, Lontrel®, Starane®, Garlon®, Baton®, Butress®, Trifolamine®
Group K	Dual®, Kerb®, Mataven®
Group L	Reglone®, Gramoxone®, Nuquat®, Spraytop®, Sprayseed®
Group M	Glyphosate, Glyphosate CT®, Sprayseed®, Roundup CT®, Touchdown®, Pacer®, Weedmaster®

List of commonly used products only
List of products does not necessarily imply state registration
Check that product is registered in your state before use Groups G and J not included

Source: DPI NSW

6.3 Herbicide tolerance ratings

Growers use pulses in their crop sequence to expand weed control options and improve soil nitrogen reserves. However, some pulse varieties and strains of rhizobia are sensitive to some herbicides (Table 2).

10 GRDC Integrated weed management, Section 4: Tactics for managing weed populations, https://grdc.com.au/resources-and-publications/iwmhub

11 Agriculture Victoria. Monitoring Tools. http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

Table 2: *Lupin variety response to herbicides in NSW, 1996–2015.*

Herbicide		Triflur®480 IBS	Stomp® IBS	Terbyne® IBS	Boxer Gold® IBS	Simagranz 900 g/litre	Brodal® Options 8–10 Leaf	Eclipse® 100SC	Eclipse® 6–10 leaf	Avadex®Xtra IBS	Status®	Sencor750® PSPE	Sniper® 2–6 Leaf	Sencor750® 6-10leaf	Terbyne® PSPE	Simagranz® 900 Cot-2leaf	Diflufenican + metribuzin	Gesatop + Gesaprim	Diuron®500 IBS	Eclipse® + Brodal® 2–6 leaf
		Trifluralin	Pendimethalin	Terbyne	Boxer Gold	Simazine	Diflufenican	Metosulam	Metosulam	Triallate	Clethodim	Metribuzin	Picolinafen	Metribuzin	Terbyne	Simazine	Diflufenican + metribuzin	Simazine = Atrazine	Diuron	Metosulam + Diflufenican
Variety	**Years tested**	**2000–2015**	**1997–2014**	**2010–2015**	**2008, 09,15**	**1998–2015**	**1996–2015**	**1996–2015**	**1996–2008**	**2002–2010**	**1999, 2013–2015**	**1997–2015**	**2000–2012**	**2004–2012**	**2010**	**2010**	**2003**	**2009**	**2009**	**2009**
Coromup	2008	✓(1)	✓(1)	-	-	N(1/1)	✓(1)	N(1/1)	-	-	-	✓(1)	✓(1)	N(1/1)	-	-	-	-	-	-
Gunyidi	2014	✓(1)	✓(1)	✓(1)	-	✓(1)	✓(1)	✓(1)	-	-	✓(1)	✓(1)	-	-	-	-	-	-	-	-
Jenabillup⒫	2010–2015	✓(4)	✓(3)	8(1/3)	✓(1)	✓(4)	N(1/4)	12(1/4)	-	-	10(1/3)	✓(4)	-	-	✓(1)	-	N(1/1)	N(1/1)	-	-
Jindalee⒫	1997–2014	N(1/10)	N(1/10)	✓(2)	-	N(2/11)	N(2/8)	13–15(2/8)	N(1/6)	✓(2)	N(1/2)	✓(8)	N(1/4)	N(1/2)	✓(1)	-	✓(1)	7(1/1)	-	-
Kalya	1998–1999	-	-	-	-	✓(2)	11(1/1)	N(1/2)	✓(1)	-	✓(1)	✓(2)	-	-	-	-	-	-	-	-
Kiev Mutant	1996–2008	✓(8)	✓(8)	-	-	N(5/9)	N(1/6)	✓(7)	✓(8)	✓(2)	✓(1)	N(2/6)	N(1/5)	N(2/3)	-	-	-	-	-	-
Luxor⒫	2004–2015	✓(7)	✓(7)	6(1/4)	11(1/3)	N(2/7)	✓(7)	✓(6)	✓(1)	✓(2)	✓(3)	N(2/7)	✓(3)	N(3/3)	12(1/2)	N(1/1)	N(1/1)	N(1/1)	✓(1)	8(1/1)
Magna	1999	-	-	-	-	✓(1)	-	✓(1)	✓(1)	-	✓(1)	✓(1)	-	-	-	-	-	-	-	-
Mandelup⒫	2001–2015	✓(8)	✓(8)	9(1/4)	N(1/3)	N(2/8)	N(1/7)	13(1/6)	N(1/2)	8(1/3)	14(1/3)	N(2/7)	N(2/4)	N(2/3)	N(1/2)	✓(1)	N(1/1)	N(1/1)	✓(1)	✓(1)
Merrit	1996–1999	-	✓(1)	-	-	✓(2)	✓(3)	13(1/4)	14(1/3)	-	✓(1)	✓(2)	-	-	-	-	-	-	-	-
Moonah	2000–2002	✓(1)	-	-	-	N(1/1)	✓(1)	N(1/1)	N(1/1)	-	-	✓(1)	-	-	-	-	-	-	-	-
Myallie	1996–1999	-	-	-	-	✓(2)	✓(2)	N(2/3)	19(1/2)	-	✓(1)	✓(2)	-	-	-	-	-	-	-	-
PBA Barlock⒫	2013–2015	N(1/3)	✓(2)	✓(1)	✓(1)	✓(3)	✓(3)	✓(3)	-	-	✓(3)	✓(3)	-	-	✓(1)	-	-	-	-	-
PBA Gunyidi⒫	2010–2015	✓(3)	✓(2)	✓(1)	✓(1)	✓(3)	✓(3)	✓(3)	-	-	✓(2)	✓(3)	-	-	✓(1)	-	✓(1)	N(1/1)	-	-
PBA Jurien⒫	2014–2015	✓(2)	N(1/1)	✓(1)	✓(1)	✓(2)	N(1/2)	N(1/2)	-	-	12(1/2)	19(1/2)	-	-	-	-	-	-	-	-
Quilinock	2000–2005	✓(7)	✓(6)	-	-	N(1/7)	N(1/3)	✓(3)	N(2/5)	✓(2)	-	N(2/4)	N(1/4)	N(1/2)	-	-	-	-	-	-
Rosetta⒫	2004–2015	✓(7)	✓(7)	N(1/4)	✓(3)	N(1/7)	✓(7)	N(1/6)	✓(1)	✓(2)	✓(3)	N(2/7)	✓(3)	N(2/3)	N(1/2)	4(1/1)	-	-	✓(1)	✓(1)
Tanjil	1998	-	-	-	-	✓(1)	✓(1)	N(1/1)	-	-	-	N(1/1)	-	-	-	-	-	-	-	-
Walan2448	2014–2015	✓(2)	✓(1)	✓(1)	✓(1)	✓(2)	✓(2)	✓(2)	-	-	10(1/2)	✓(2)	-	-	-	-	-	-	-	-
Walan2474	2014	10(1/1)	✓(1)	✓(1)	-	✓(1)	✓(1)	9(1/1)	-	-	11(1/1)	✓(1)	-	-	-	-	-	-	-	-
Walan2498	2015	✓(1)	-	-	✓(1)	✓(1)	✓(1)	✓(1)	-	-	✓(1)	✓(1)	-	-	-	-	-	-	-	-
Wk338	2014–2015	✓(2)	✓(1)	✓(1)	✓(1)	✓(2)	✓(2)	✓(2)	-	-	✓(2)	N(1/2)	-	-	-	-	-	-	-	-
Wonga⒫	1996–2010	✓(8)	✓(9)	N(1/1)	14(1/2)	N(2/10)	N(2/7)	8(1/8)	14–24(2/7)	✓(4)	✓(1)	N(2/7)	N(1/5)	N(2/3)	N(1/1)	✓(1)	N(1/1)	N(1/1)	16(1/1)	✓(1)
Rates (product/ha)		1.7 L	3.0 L	1.4 L	2.5 L	1.667 L	200 ml	70 ml	10 g	1.6 L	375 ml	380 g	50 g	380 g	1.0 L	550 g	100 ml + 150 g	1.3 kg + 650 g	2.0 L	7 g + 100 ml
Crop stage at spraying		IBS	IBS	IBS	IBS	PSPE	8–10 leaf	2–6 leaf	6–10 leaf	IBS	4 leaf	PSPE	2-6leaf	6–10 leaf	PSPE	Cot-2 leaf	PSPE	IBS	IBS	2–6 leaf

Herbicide		Eclipse® 2–6 leaf	Gesatop®900W + Brodal	Simazine 4–6 leaf	Sencor750® + Brodal	Simazine900 + Brodal® 4–6 leaf	Dual Gold® IBS	Dual Gold® PSPE	Motsa®	Simazine + Brodal® IBS	Simazine + Brodal® PSPE	Simazine + Brodal® 6–10 leaf	Eclipse® Mid-flowering	Eclipse® mid-podding	Targa®	Eclipse® + Brodal® 4–8 leaf	Verdict®520	Sertin®	Simazine + Atrazine IBS	Simazine + Atrazine PSPE	Simazine + Trifluralin IBS	Sakura®850WG IBS
		Metosulam	Simazine + Diflufenican	Simazine	Metribuzin + Diflufenican	Simazine + diflufenican	S-Metolachlor	S-Metolachlor	Clethodim + Haloxyfop	Simazine + Diflufenican	Simazine + Diflufenican	Simazine + Diflufenican	Metosulam	Metosulam	Quizalofop-P-ethyl	Metosulam + Diflufenican	Haloxyfop-R	Sethoxydim	Simazine + Atrazine	Simazine + Atrazine	Simazine + Trifluralin	Sakura® 850WG
Variety	Years tested	2009	2009	2004	2004	2005	2002–2004	2002	2004	1998	1997–2002	1996	2002–2003	2002–2003	2002	2001	1998–2001	1998–2000	1997–1998	1998–2000	1998	2012
Coromup	2008	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gunyidi	2014	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jenabillupⓓ	2010–2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓(1)	-	-	-	N(1/1)
Jindaleeⓓ	1997–2014	-	-	✓(1)	N(1/1)	N(1/1)	8(1/1)	✓(3)	✓(1)	✓(1)	✓(2)	-	7(1/2)	✓(2)	✓(1)	✓(1)	✓(3)	✓(3)	✓(2)	16(1/2)	✓(1)	-
Kalya	1998–1999	-	-	-	-	-	✓(1)	✓(3)	-	✓(1)	✓(1)	-	-	-	-	-	✓(1)	✓(1)	✓(1)	15(1/2)	✓(1)	-
Kiev Mutant	1996–2008	-	-	✓(1)	11(1/1)	N(1/1)	-	-	✓(1)	-	✓(3)	N(1/1)	N(1/2)	✓(2)	✓(1)	✓(1)	✓(2)	✓(1)	✓(1)	N(2/2)	-	-
Luxorⓓ	2004–2015	✓(1)	✓(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓(1)	-	-	-	6(1/1)
Magna	1999	-	-	-	-	-	-	-	-	-	✓(1)	-	-	-	-	-	-	-	-	N(1/1)	-	-
Mandelupⓓ	2001–2015	N(1/1)	N(1/1)	-	-	-	✓(1)	✓(1)	-	-	-	-	8(1/1)	✓(1)	✓(1)	-	-	✓(1)	-	-	-	N(1/1)
Merrit	1996–1999	-	-	-	-	-	-	-	-	✓(1)	✓(2)	18(1/1)	-	-	-	-	✓(1)	✓(1)	N(1/2)	12(1/2)	✓(1)	-
Moonah	2000–2002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓(1)	✓(1)	-	✓(1)	-	-
Myallie	1996–1999	-	-	-	-	-	-	-	-	✓(1)	✓(1)	N(1/1)	-	-	-	-	✓(1)	✓(1)	✓(1)	N(1/2)	✓(1)	-
PBA Barlockⓓ	2013–2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PBA Gunyidiⓓ	2010–2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓(1)	-	-	-	-
PBA Jurienⓓ	2014–2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quilinock	2000–2005	-	-	✓(1)	14(1/1)	N(1/1)	✓(1)	✓(3)	N(1/1)	-	✓(1)	-	12(1/2)	✓(2)	✓(1)	✓(1)	✓(2)	✓(1)	-	✓(1)	-	-
Rosettaⓓ	2004–2015	✓(1)	✓(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓(1)	-	-	-	✓(1)
Tanjil	1998	-	-	-	-	-	-	-	-	✓(1)	-	-	-	-	-	-	✓(1)	✓(1)	✓(1)	17(1/1)	✓(1)	-
Walan2448	2014–2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Walan2474	2014	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Walan2498	2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wk338	2014–2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wongaⓓ	1996–2010	21(1/1)	✓(1)	✓(1)	15(1/1)	N(1/1)	✓(1)	✓(3)	✓(1)	✓(1)	✓(3)	22(1/1)	13(1/2)	✓(2)	N(1/1)	✓(1)	✓(3)	✓(2)	✓(2)	N(2/3)	✓(1)	-
Rates (product/ha)		70 ml	556 g + 150 ml	1.5 L	133 g + 100 ml	1.0 L + 150 ml	1.0 L	1.0 L	300 ml	1.0 L + 75 ml	1.0 L + 150 ml	2.0 L + 200 ml	7 g	7 g	375 ml	5 g + 100 ml	100 ml	1.0 L	2.0 L + 1.0 L	2.0 L +1.0 L	1.5 L + 1.5 L	118 g
Crop stage at spraying		2–6 leaf	2–6 leaf	4–6 leaf	3 leaf	4–6 leaf	IBS	PSPE	6–8 leaf	IBS	PSPE	8–10 leaf	Mid flower	Mid pod	2–6 leaf	4–8 leaf	6–10 leaf	6 leaf	IBS	PSPE	IBS	IBS

The sensitivity of the variety compared to unsprayed controls of the same varietyis summarised, using the following symbols based on the yield responses across all trials:

- not tested or only tested at higher than recommended rate (Please check Preliminary Evaluation tables

MORE INFORMATION

NVT – Lupin herbicide tolerance 1996 - 2015

✓ no significant yield reductions at higher than recommended rates in (Z) trials
N (narrow margin) significant yield reductions at higher than recommended rate in 1+ trials ONLY
x% yield reduction (warning) significant yield reduction at recommended rate in 1 trial only
x-y% yield reductions (warning) significant yield reductions at recommended rate in 2+ trials

Always follow label recommendations. All pesticide applications must accord with the currently registered label forthat particular pesticide, crop, pest and region. Any research regarding pesticides or their use reported in this website does not constitute a recommendation for that particular use by the authors, the author's organisations or ACAS. It must be emphasised that crop tolerance and yield responses to herbicides are strongly influenced by seasonal conditions.

Source: NVT

Check the APVMA website for up to date registrations, labels and recommendations.

6.4 Pre-emergent herbicides

Pre-emergent herbicides control weeds between radicle (root shoot) emergence from the seed and seedling emergence through the soil. Some pre-emergent herbicides may also provide post-emergent control.

In 2016, the Boxer Gold registration was expanded to incorporate a range of pulse crops. Boxer Gold can now be applied pre-planting at 2.5 L/ha to lupins, chickpeas, faba bean, field pea and lentils to control of annual ryegrass, silver grass, stone crop and toadrush. [12]

See NSW DPI – Weed Control in Winter Crops 2017.

IN FOCUS

Pre-emergent herbicide options for annual ryegrass control in Albus Lupins, 2014

Annual ryegrass (ARG) is developing herbicide resistance to many in-crop herbicides and in most cases multiple modes of action. In many paddocks, most of the Group A Fop herbicides are no longer effective nor are the common Group B herbicides like Logran. As a result, on a number of farms where ARG levels are increasing through the cereal phase of crop rotations the aim has been to reduce these weed populations in the broadleaf phases with products such as clethodim which has traditionally exhibited less resistance.

However, a herbicide resistance survey undertaken by the Grain Orana Alliance (GOA) in the Central West of NSW in 2013 [13] revealed 22% of ARG samples submitted demonstrated resistance to clethodim (and a number of other herbicides) and for many of these populations there are few effective alternative herbicide options left. The remaining effectiveness of this product must be protected as best as possible to prolong its useful life and using it to control large populations of ARG may be exposing the product to excessive resistance selection pressure.

A GOA trial was designed to investigate a number of pre-emergent herbicide options aimed at reducing the populations that clethodim may be targeted at in-crop and hence the risk of resistance developing.

Trials were established in growers' paddocks with known populations of ARG in Narromine and Gilgandra, NSW. Herbicide treatments were applied ahead of growers seeding equipment by an All Terrain Vehicle mounted boom and incorporated by the growers' equipment. Any PSPE applications were applied after seeding before crop emergence. Resultant weed control was assessed a number of times before the site was sprayed out with herbicides to prevent seed set.

12 G Brooke, C McMaster (2016) Weed control in Winter crops 2016. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops

13 M Street (2013) Report on the 2013 GOA Herbicide Resistance Survey. http://www.grainorana.com.au/documents?download=29

Results - Narrowmine

There was no impact on crop establishment by the different treatments compared to the nil treatment. The trial has demonstrated that using any of the pre-emergent herbicides tested significantly reduced ARG populations, however there were differences between the treatments in their level of control. An application of simazine alone, which in the past has probably been the most common pre-emergent herbicide used in lupins in this region, reduced ARG populations by more than half however still leaving a weed population of 12 plants/m^2. Terbyne, trifluralin and Outlook all resulted in a similar level of residual weeds population resulting in an average level of control of 54%. The newer herbicides in Boxer Gold and Sakura were the best performing options as single product treatments with around 80% control. Tank mixed or multiple product herbicide treatments provided statistically similar reductions to the ARG population of approximately 80% with residual weed population of around 6–7 plants/m^2.

The resulting control achieved by the use of multiple products was often greater than that achieved when the products were used alone. In many cases the mixing or use of multiple products resulted in almost an additive effect, as can be seen in Figure 4 and for example:

- Adding trifluralin to either simazine or Terbyne increased control from ~50% to ~75% nearly halving the residual weed numbers,
- Outlook applied with either simazine or Terbyne nearly doubled ARG control,
- Avadex combined with trifluralin resulted in approximately 73% control compared to only 57% control from trifluralin alone.

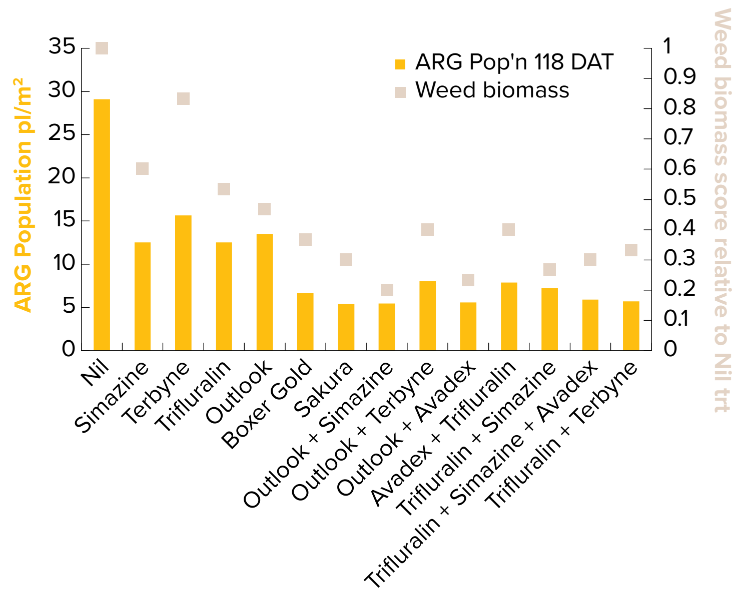


Figure 1: *ARG populations and relative weed biomass at 118 days after application in response to various pre-emergent herbicide treatments.*

Source: GOA

Results – Gilgandra

There was no impact on crop establishment by the different treatments compared to the nil treatment. All treatments applied resulted in a reduction in ARG population compared to the Nil treatment with the exception of Terbyne (at the earlier assessment date) as shown in Figure 5. At the later assessment, all products resulted in a reduction in ARG populations.

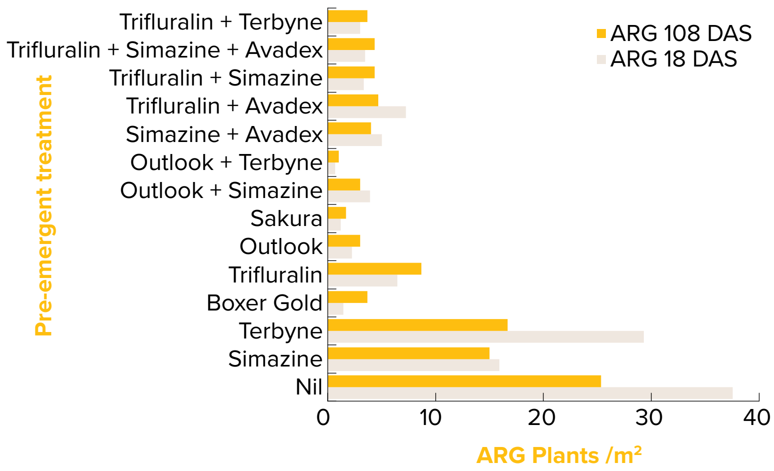


Figure 2: *ARG populations at 18 and 108 days after various pre-emergent herbicide treatments.*

Source: GOA

The trial demonstrated that using any of the pre-emergent herbicides tested reduced ARG population, however there were differences between the treatments in their level of control. A single application of Simazine, which in the past has probably been the most common pre-emergent herbicide used in lupins in the region, reduced ARG populations by less than half, with residual weed populations of around 15 plants/m^2. Terbyne resulted in a similar level of residual weed population. Alternate single product pre-emergent options; Boxer Gold, Outlook and Sakura all resulted in much better levels of control than simazine alone with residual ARG populations of only 1–3 plants/m^2. Trifluralin offered improved control over simazine but not quite as good as the options listed above. Tank mixing herbicide options or multiple product approaches in general showed improved control over that achieved by those products applied alone. In many cases the resultant control was almost the addition of the control achieved by each of the components. The results indicate a number of herbicides, such as trifluralin or Outlook, when mixed with the district standard of simazine improved control. An interesting point to note is the addition of Avadex to trifluralin in this trial has improved the control of the ARG although not statistically different to the use of trifluralin alone. However, control may have been slightly more persistent as evidenced by comparing the later control levels.

Conclusion

This trial has demonstrated that the use of pre-emergent herbicides can reduce ARG populations which in turn will reduce the 'pressure' growers would be applying for the development of resistance to clethodim. This trial has demonstrated that the common practice of just simazine provides only moderate control of ARG populations, and that there are a number of other options that are far more effective.

In this trial the newer herbicides Sakura and Boxer Gold showed improved weed control over that of common practice. It also demonstrated the advantage or improved control that can be achieved through combinations of products, for example the addition of trifluralin to simazine resulted in control that matched that of Boxer Gold and Sakura (with a significantly lower cost). Growers and advisors should not base their pre-emergent ARG control options solely on the results presented in this report. Consideration should also be given to results from other trials and should also take into account the following:

- What other weeds are present and the effectiveness of the alternatives are on these?
- What is the cost of these alternatives in comparison to each other?
- Any varietal differences in crop tolerances of the particular alternatives?
- Plant back or residue considerations?
- Herbicide rotations and resistance management?
- The herbicide resistance status of the weeds you are targeting. [14]

6.4.1 Incorporation by sowing

Application of pre-emergent herbicides pre-sowing and then incorporating them into the seed bed during the sowing process will often increase safety to crops because the sowing operation removes a certain amount of herbicide away from the seed row. This can conversely reduce weed control for the very same reason, as chemical is moved out of the seed row. In this case, it is wise to include a water soluble herbicide into the mix aiming to have some herbicide wash into the seed furrow.

The preferred method of applying pre-emergent herbicides in conservation farming systems is by incorporation by sowing, as crop safety is maximised, stubble remains standing to protect the seedbed, and soil disturbance is minimised.

Incorporation by sowing (IBS) is when a herbicide is applied just before sowing (usually in conjunction with a knockdown herbicide such as glyphosate) and soil throw from the sowing operation incorporates the herbicide into the seedbed.

Benefits and issues for pre-emergent herbicides

- The residual activity of pre-emergent herbicides controls the first few flushes of germinating weeds while the crop or pasture is too small to compete.
- Good planning is needed to use pre-emergent herbicides as an effective tactic. It is necessary to consider weed species and density, crop or pasture type, soil condition and rotation of crop or pasture species.
- Soil activity and environmental conditions at the time of application play an important role in the availability, activity and persistence of pre-emergent herbicides.
- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [15]

The important factors in getting pre-emergent herbicide to work effectively while minimising crop damage are:

- to understand the position of the weed seeds in the soil; the soil type (particularly amount of organic matter and crop residue on the surface);
- the solubility of the herbicide; and
- its ability to be bound by the soil.

14 GOA (2015) Pre-emergent herbicide options for annual ryegrass control in Albus Lupins, 2014. Grain Orana Alliance. http://www.grainorana.com.au/search

15 DAFWA. (2016) Herbicides. https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2

6.4.2 Understanding pre-emergent herbicides

With the increasing incidence of resistance to post-emergent herbicides across Australia, pre-emergent herbicides are becoming more important for weed control. Pre-emergent herbicides typically have more variables that can affect efficacy than post-emergent herbicides. Post-emergent herbicides are applied when weeds are present and usually the main considerations relate to application coverage, weed size and environmental conditions that impact on performance. Pre-emergent herbicides are applied before the weeds germinate and a number of other considerations come into play. The various pre-emergent herbicides behave differently in the soil and may behave differently in different soil types. Therefore, it is essential to understand the behaviour of the herbicide, the soil type and the farming system in order to use pre-emergent herbicides in the most effective way.

Pre-emergent herbicides have to be absorbed by the germinating seedling from the soil. To do so, these herbicides need to have some solubility in water and be in a position in the soil to be absorbed by the roots or emerging shoot. The dinitroaniline herbicides, such as trifluralin, are an exception in that they are absorbed by the seedlings as a gas. These herbicides still require water in order to be released from the soil as a gas. Therefore, weed control with pre-emergent herbicides will always be lower under dry conditions.

6.4.3 Behaviour of pre-emergent herbicides in the soil

Behaviour of pre-emergent herbicides in the soil is driven by three key factors:

- solubility of the herbicide,
- how tightly the herbicide is bound to soil components, and
- the rate of breakdown of the herbicide in the soil.

Characteristics of some common pre-emergent herbicides are given in Table 3.

The water solubility of herbicides ranges from very low values for trifluralin to very high values for chlorsulfuron. Water solubility influences how far the herbicide will move in the soil profile in response to rainfall events. Herbicides with high solubility are at greater risk of being moved into the crop seed row by rainfall and potentially causing crop damage. If the herbicides move too far through the soil profile they risk moving out of the weed root zone and failing to control the weed species at all. Herbicides with very low water solubility are unlikely to move far from where they are applied.

Table 3: *Water solubility, binding characteristics to soil organic matter and degradation half-life for some common pre-emergent herbicides.*

Herbicide	Water solubility		Koc		Degradation half-life (days)
	mg L-1 (at 20 C and neutral pH)	Rating	mL g-1 (in typical neutral soils)	Rating	
Trifluralin	0.22	Very low	15,800	Very high	181
Pendimethalin	0.33	Very low	17,800	Very high	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	3000	High	82
Prosulfocarb	13	Low	2000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	75.5
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23

Herbicide	Water solubility		Koc		Degradation half-life (days)
	mg L-1 (at 20 C and neutral pH)	Rating	mL g-1 (in typical neutral soils)	Rating	
Chlorsulfuron	12,500	Very High	40	Low	160

The important factors in getting pre-emergent herbicides to work effectively while minimising crop damage are: to understand the position of the weed seeds in the soil; the soil type (particularly amount of organic matter and crop residue on the surface); the solubility of the herbicide; and its ability to be bound by the soil. Managing all these factors is complex, but some rules of thumb are:

1. Soils with low organic matter are particularly prone to crop damage from pre-emergent herbicides (especially sandy soils) and rates should be reduced where necessary to lower the risk of crop damage.
2. The more water-soluble herbicides will move more readily through the soil profile and are better suited to post sowing pre-emergent applications than the less water soluble herbicides. They are also more likely to produce crop damage after heavy rain.
3. Pre-emergent herbicides need to be at sufficient concentration at or below the weed seed (except for triallate which needs to be above the weed seed) to provide effective control. Keeping weed seeds on the soil surface will improve control by pre-emergent herbicides.
4. High crop residue loads on the soil surface are not conducive to pre-emergent herbicides working well as they keep the herbicide from contact with the seed. More water soluble herbicides cope better with crop residue, but the solution is to manage crop residue so that at least 50% of the soil surface is exposed at the time of application.
5. If the soil is dry on the surface, but moist underneath there may be sufficient moisture to germinate the weed seeds, but not enough to activate the herbicide. Poor weed control is likely under these circumstances. The more water soluble herbicides are less adversely affected under these conditions.
6. Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular care needs to be taken with disc seeding equipment in choice of product and maintaining an adequate seeding depth. [16]

Top tips for using pre-emergent herbicides:

- Only use pre-emergent herbicides as part of an integrated weed control plan including both chemical and non chemical weed control practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header
- Minimise soil disturbance allowing weed seeds to remain on the soil surface.
- Leave stubble standing rather than laying it over.
- Knife points and press wheels allow greatest crop safety. Avoid harrows.
- If using a disc seeder understand the mechanics of your machine and the limitations it may carry compared to a knife point and press wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter row whilst maintaining a seed furrow free from herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the seed.
- IBS rather than PSPE for crop safety.

16 Preston C. (2014). Understanding pre emergent cereal herbicides. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides

MORE INFORMATION

Using pre-emergent herbicides in conservation farming systems.

Gearing up to use pre-emergent herbicides.

GRDC Pre-emergent herbicides Factsheet.

How pre-emergent herbicides work.

Seeding systems and pre emergence herbicides

- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [17]

6.5 Post-plant pre-emergent herbicides

Post-sowing, pre-emergent herbicides use is when a pre-emergent herbicide is applied after sowing (but before crop emergence) to the seedbed.

Post-plant pre-emergent herbicides are primarily absorbed through the roots, but there may also be some foliar absorption (e.g. Terbyne®). When applied to soil, best control is achieved when the soil is flat and relatively free of clods and trash. Sufficient rainfall (20–30 mm) to wet the soil through the weed root-zone is necessary within 2–3 weeks of application. Best weed control is achieved from Pre-sowing, Pre-emergence application because rainfall gives the best incorporation. Mechanical incorporation pre-sowing is less uniform, and so weed control may be less effective. If applied pre-sowing and sown with minimal disturbance, incorporation will essentially be by rainfall after application. Weed control in the sowing row may be less effective because a certain amount of herbicide will be removed from the crop row.

Simazine is widely applied in lupins post-sowing pre-emergence. It is a broad-spectrum residual herbicide that controls a wide range of broadleaf weeds and grasses for a 4–8 week period. [18]

For more information, see the NSW DPI Weed control in Winter crops 2016.

6.6 In-crop herbicides: knock downs and residuals

Key points for in-crop herbicide application:

- Knowledge of a product's translocation and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.
- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.
- Robust rates of products and appropriate water rates are often more important for achieving control than the nozzle type, but, correct nozzle type can widen the spray window, improve deposition and reduce drift risk.
- Travel speed and boom height can affect control and drift potential.
- Appropriate conditions for spraying are always important. [19]

Many weed populations have some tolerance to post-emergent herbicides.

17 Haskins B. DPI NSW. Using pre-emergent herbicides in conservation farming systems. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

18 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

19 GRDC Factsheets: In-crop herbicide use. (2014). https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/08/grdc-fs-incropherbicideuse

6.6.1 Herbicide registration according to growth stage

Table 4: *Registered herbicides for use in lupin according to growth stage.*

MOA	Herbicide	Growth stage
Group A	butroxydim + fluazifop	Up to 4 weeks before harvest
	clethodim	Up to 80% of flowers open
	fluazifop	Up to 17 weeks before harvest
	haloxyfop	2nd leaf/node through to flowering
	propaquizafop	Up to 6 weeks before harvest
	quizalofop	Up to 15 weeks before harvest
	sethoxydim	Up to prior to flowering
	tepraloxydim	Up to 12 weeks before harvest
Group B	metosulam	From 2–10 leaf
	imazamethapyr	No restriction, but specified varieties only
Group F	diflufenican	From 2 leaf through to flowering
	picolinafen	From 2 – 6 leaf

*Note: For pulses, the window for application for selective grass control herbicides (Group A) is generally dictated by regulatory requirements to avoid residues in produce that exceed levels acceptable to various markets. Check the labels for individual herbicides but pulse crop safety for most Group As is not influenced by growth stage up to at least flowering.

For up to date chemical Witholding Periods and other label information, see the APVMA search facility.

See NSW DPI – Weed Control in Winter Crops 2017, for more information on registered in-crop herbicides and their use.

In-crop herbicides will normally require a different set of nozzles compared to those used in summer fallow spraying and application of pre-emergent herbicides.

In-crop post-emergent herbicides should be applied as an upper-end medium to lower-end coarse droplet spectrum depending on the particular herbicide being used.

Remember that this must be combined with the relevant application volume to get enough droplets per square centimetre on the target to achieve good coverage. You must also match the nozzles to your spray rig, pump and controller and desired travel speed.

Operate within the recommended ground speed range and apply the product in a higher application volume. The actual recommended application volume will vary with the product and situation, so read the label and follow the directions.

How to get the most out of post-emergent herbicides:

Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical.

Consider the growth stage of the crop.

- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species were historically in the paddock and the resistance status of the paddock (if unsure, send plants away for a 'Quick-Test').
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or, for some chemicals, cloudy/sunny days. This is especially pertinent
- for frosts with grass-weed chemicals.
- Use the correct spray application:
- Consider droplet size with grass-weed herbicides, water volumes with contact chemicals and time of day.

MORE INFORMATION

GRDC In-crop herbicide use Factsheet.

Pre-harvest herbicide use factsheet

- Observe the plant-back periods and withholding periods.
- Consider compatibility if using a mixing partner.
- Add correct adjuvant. [20]

6.6.2 In-crop herbicide plant-back intervals

Be sure to adhere to plant-back intervals (Table 5). Always read the label.

Table 5: *Guidelines for crop rotations – In-crop herbicides.*

	Ally®[1]	Amicide® Advance (700 g/L)[2]	Atlantis® O[4]	Atrazine	Balance® (NNSW)[6]	Boxer® Gold	Broadstrike™[11]		Cadence[2]	Eclipse® 100 SC	Tackle®			Hotshot™	Hussar® OD	Intervix®	Kamba® 500[2]
Herbicide group	B	I	B	C	C	J&K	B		I	B	B			I	B	B	I
Soil pH 1:5 soil:water suspension method	pH 5.6–8.5										< pH 6.5	pH 6.6–7.5	pH 7.6–8.5				
Specific details							(NNSW)	(SNSW)									
Lupins	9 mo		9 mo		–		6[12]–9[13] mo	9[12]–12[13] mo			12 mo	22 mo	–		9 mo	10 mo	

	Logran Bpower®[5 16]				Lontrel™ Advanced (600 g/L)	LV Ester 680 (680 g/l)[2]	Midas®	Monza®[3]		On Duty®		Precept® 150 EC				Prometryn 900 DF	Raptor®	Sakura® 850 WG	Simazine	Spinnaker®	Starane™	FallowBoss™ Tordon™	Velocity®			
Herbicide group	B				I	I	B	B		B		I + H				C	B	K	C	B	I	I	H + C			
Soil pH 1:5 soil:water suspension method	pH <6.5	pH 6.6–7.5	pH 7.6–8.5	pH>8.6				pH<6.5	pH 6.5–8.5			All soils	All soils	pH <6.5	Alkaline								All soils	pH <7.0	pH <6.0	pH 7.0–8.4
Specific details										20 g/ha	40 g/ha	1.0 L/ha 250mm[18]	2.0 L/ha 250mm[18]	2.0 L/ha 250mm[18]	2.0 L/ha 500 mm								0.67 L/ha 250mm[18]	1.0 L/ha 250mm[18]	1.0 L/ha 250mm[18]	1.0 L/ha 500 mm
Lupins	12 mo			24 mo			10 mo	10 mo		8 mo	8 mo	9 mo	9 mo	9 mo				9 mo								

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

1 = For pH 8.6 and above tolerance of crops (grown through to maturity) should be determined on a small scale, in the previous season,

20 WeedSmart. Post-emergents. http://www.weedsmart.org.au/post-emergents/

before sowing into larger areas.
2 = When applied to dry soils at least 15 mm of rain must fall prior to the commencement of the plant-back period.
3 = Additional rainfall/soil moisture requirements need to be observed – see label.
4 = Rainfall of less than 250 mm following Atlantis® OD use will result in extended re-cropping intervals for winter crops sown the following season. Patchy rain with extended dry periods may also extend this period. Rainfall of less than 500 mm may result in extended re-cropping periods for summer crops in the following year. Rainfall of less than 500 mm may result in extended re-cropping periods for summer crops in the following year. Use in soil above pH 8.5 is not recommended.
5 = pH < 8.0 (under conditions of good seasonal rainfall) = 9 months, pH > 8.0 = 21 months.
6 = Prolonged dry periods or cold conditions may result in extended re-cropping intervals, even if rainfall exceeds the required amount. Use on soils with pH less than 7.0 may result in extend recropping intervals. Cultivation is recommended prior to recropping.
7 = 100 mm minimum rainfall total between herbicide application and planting of subsequent crop.
8 = 250 mm minimum rainfall total between herbicide application and planting of subsequent crop.
9 = 350 mm minimum rainfall total between herbicide application and planting of subsequent crop.
10 = 500 mm minimum rainfall total between herbicide application and planting of subsequent crop.
11 = For SNSW a minimum of 25 mm (preferably 50 mm) and NNSW a minimum of 50 mm (preferably 100 mm) must fall over the warmer months of the year. On shallow, duplex, low O.M. soils of less than 30 cm, do not plant until 2 years after application.
12 = 25 g/ha.
13 = 50 g/ha.
14 = Tackle is not recommended on soils of pH 8.6 and above.
15 = Additional requirements need to be met for certain non clearfield cereals – see label.
16 = Where Lonestar® is applied at lower rates with trifluralin or post-emergent additional requirements need to be considered – see label.
17 = Wheat (0 months), durum wheat (21 months).
18 = Minimum of 300 mm for summer crops. Minimum 500 mm for Cotton, Soybean and Sunflower where Precept® 150 rate up to 2.0 L/ha. See Precept® label.
19 = Plantback refers to pasture legumes

Source: NSW DPI, 2016 Pages 10 and 11

MORE INFORMATION

Weed control in Winter crops 2017

6.7 Withholding periods

Table 6 lists the specific withholding periods that apply to lupin. All other withholding periods can be found in the NSW DPI Weed Control in Winter Crops Guide.

Table 6: *Withholding periods specific to lupin in NSW.*

Eclipse® 100 SC® has a 28 day stock withholding period in lupin.
Elantra® Xtreme® has a 42 day harvest withholding period in lupin.
Fusilade® Forte has a 49 day stock withholding period and 119 harvest withholding period in lupin.
Shogun® has a 105 day harvest withholding period in lupin.
Verdict™ 520 has a 28 day stock withholding period in lupin.

Source: NSW DPI

6.8 Conditions for spraying

When applying herbicides, the aim is to maximise the amount reaching the target and to minimise the amount reaching off-target areas. This results in:

- improved herbicide effectiveness
- reduced damage and/or contamination of off-target crops and areas.

In areas where several agricultural enterprises coexist, conflicts can arise, particularly from the use of herbicides. All herbicides are capable of drift.

When spraying a herbicide, you have a moral and legal responsibility to prevent it from drifting and contaminating or damaging neighbours' crops and sensitive areas.

All grass herbicide labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions (Photo 2). Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, likely resulting in incomplete kill or only suppression of weeds:

- moisture stress (and drought)
- waterlogging
- high temperature–low humidity conditions
- extreme cold or frosts
- nutrient deficiency, especially effects of low N
- use of pre-emergent herbicides that affect growth and root development; i.e. simazine, Balance®, trifluralin, and Stomp®

- excessively heavy dews resulting in poor spray retentions on grass leaves

Photo 2: *Boom spray on crop.*

Source: DAFWA

Ensure that grass weeds have fully recovered before applying grass herbicides.

6.8.1 Minimising spray drift

Before spraying

- Always check for susceptible crops in the area, for example broadleaf crops such as grape vines, cotton, vegetables and pulses, if you are using a broadleaf herbicide.
- Check sensitive areas such as houses, schools, waterways and riverbanks.
- Notify neighbours of your spraying intentions.

The Cotton Field Awareness Map is provided free of charge with the purpose of minimising off-target damage from downwind pesticide application, particularly during fallow spraying. Users can also access the map to check the location of the paddock(s) they may be planning to spray to assess the proximity of the nearest cotton crop.

During spraying

- Always monitor weather conditions carefully and understand their effect on 'drift hazard'.
- Do not spray if conditions are not suitable, and stop spraying if conditions change and become unsuitable.
- Record weather conditions (especially temperature and relative humidity), wind speed and direction, herbicide and water rates, and operating details for each paddock.
- Supervise all spraying, even when a contractor is employed. Provide a map marking the areas to be sprayed, buffers to be observed and sensitive crops and areas.
- Spray when the temperature is less than 28°C.
- Where surface temperature inversion conditions exist, it is unsafe for spraying due to the potential for spray drift.

- Maintain a downwind buffer. This may be in-crop, for example keeping a boom's width from the downwind edge of the field.
- Minimise spray release height.
- Use the largest droplets that will give adequate spray coverage.
- Always use the least-volatile formulation of herbicide available.
- If there are sensitive crops in the area, use the herbicide that is the least damaging.

6.8.2 Types of drift

Sprayed herbicides can drift as droplets, as vapours or as particles:

- *Droplet drift* is the easiest to control because, under good spraying conditions, droplets are carried down by air turbulence and gravity, to collect on plant or soil surfaces. Droplet drift is the most common cause of off-target damage caused by herbicide application. For example, spraying of fallows with glyphosate under the wrong conditions often leads to severe damage to establishing crops.
- *Particle drift* occurs when water and other herbicide carriers evaporate quickly from the droplet, leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. This form of drift has damaged susceptible crops up to 30 km from the source.
- *Vapour drift* is confined to volatile herbicides such as 2,4-D ester. Vapours may arise directly from the spray or evaporation of herbicide from sprayed surfaces. Use of 2,4-D ester in summer can lead to vapour drift damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans and grapes. This may occur hours after the herbicide has been applied.

In 2006, the Australian Pesticides and Veterinary Medicines Authority (APVMA) restricted the use of highly volatile forms of 2,4-D ester. The changes are now seen with the substitution of lower volatile forms of 2,4-D and MCPA. Products with lower 'risk' ester formulations are commonly labelled with LVE (low volatile ester). These formulations of esters have a much lower tendency to volatilise, but caution should remain as they are still prone to droplet drift.

Vapours and minute particles float in the airstream and are poorly collected on catching surfaces. They may be carried for many kilometres in thermal updraughts before being deposited.

Sensitive crops may be up to 10,000 times more sensitive than the crop being sprayed. Even small quantities of drifting herbicide can cause severe damage to highly sensitive plants.

6.8.3 Factors affecting the risk of spray drift

Any herbicide can drift. The drift hazard, or off-target potential, of a herbicide in a particular situation depends on the following factors:

- Volatility of the formulation applied. Volatility refers to the likelihood that the herbicide will evaporate and become a gas. Esters volatilise (evaporate), whereas amines do not.
- Proximity of crops susceptible to the particular herbicide being applied, and their growth stage. For example, cotton is most sensitive to Group I herbicides in the seedling stage.
- Method of application and equipment used. Aerial application releases spray at 3 m above the target and uses relatively low application volumes, while ground-rigs have lower release heights and generally higher application volumes, and a range of nozzle types. Misters produce large numbers of very fine droplets that use wind to carry them to their target.
- Size of the area treated. The greater the area treated the longer it takes to apply the herbicide. If local meteorological conditions change, particularly in the case of 2,4-D ester, then more herbicide is able to volatilise.

- Amount of active ingredient (herbicide) applied. The more herbicide applied per hectare, the greater the amount available to drift or volatilise.
- Efficiency of droplet capture. Bare soil does not have anything to catch drifting droplets, unlike crops, erect pasture species and standing stubbles.
- Weather conditions during and shortly after application. Changing weather conditions can increase the risk of spray drift.

Volatility

Many ester formulations are highly volatile compared with the non-volatile amine, sodium salt and acid formulations. Table 8 is a guide to the more common herbicide active ingredients that are marketed with more than one formulation.

Table 7: *Relative herbicide volatility.*

Form of active ingredient	Full name	Product example
Non-volatile		
Amine salts		
MCPA DMA	dimethyl amine salt	MCPA 500
2,4-D DMA	dimethyl amine salt	2,4-D Amine 500
2,4-D DEA	diethanolamine salt	2,4-D Amine 500 Low Odour®
2,4-D IPA	isopropylamine salt	Surpass® 300
2,4-D TIPA	triisopropanolamine	Tordon® 75-D
2,4-DB DMA	dimethyl amine salt	Buttress®
dicamba DMA	dimethyl amine salt	Banvel® 200
triclopyr TEA	triethylamine salt	Tordon® Timber Control
picloram TIPA	triisopropanolamine	Tordon® 75-D
clopyralid DMA	dimethylamine	Lontrel® Advanced
clopyralid TIPA	triisopropanolamine	Archer®
aminopyralid K salt	potassium salt	Stinger®
aminopyralid TIPA	triisopropanolamine	Hotshot®
Other salts		
MCPA Na salt	sodium salt	MCPA 250
MCPA Na/K salt	sodium & potassium salt	MCPA 250
2,4-DB Na/K salt	sodium & potassium salt	Buticide®
dicamba Na salt	sodium salt	Cadence®
Some volatility		
Esters		
MCPA EHE	ethylhexyl ester	LVE MCPA
MCPA IOE	isooctyl ester	LVE MCPA
triclopyr butoxyl	butoxyethyl ester	Garlon® 600
Picloram IOE	isooctyl ester	Access®
2,4-D ehe	ethylhexyl ester	2,4-D LVE 680
fluroxypyr M ester	meptyl ester	Starane® Advanced

Source: NSW DPI

Minimising drift

A significant part of minimising spray drift is the selection of equipment to reduce the number of small droplets produced. However, this in turn may affect coverage of the target, and therefore the possible effectiveness of the pesticide application. This aspect of spraying needs to be carefully considered when planning to spray.

As the number of smaller droplets decreases, so does the coverage of the spray. A good example of this is the use of air-induction nozzles that produce large droplets that splatter. These nozzles produce a droplet pattern and number unsuitable for targets such as seedling grasses that present a small vertical target.

In 2010, APVMA announced new measures to minimise the number of spray drift incidents (Table 9). The changes are restrictions on the droplet-size spectrum an applicator can use, wind speed suitable for spraying and the downwind buffer zone between spraying and a sensitive target. These changes should be evident on current herbicide labels. Hand-held spraying application is exempt from these regulations.

Table 8: *Nozzle selection guide for ground application.*

Factor	Distance downwind to susceptible crop is <1 km	Distance downwind to susceptible crop is 1–30 km and more
Risk	High	Medium
Preferred droplet size (to minimise risk)	coarse to very coarse	medium to coarse
Volume median diameter (microns)	310	210
Pressure (bars)	2.5	2.5
Flat fan nozzle size #	11008	11004
Recommended nozzles (examples only)	Raindrop: Whirljet® Air induction: Yamaho Turbodrop® Hardi Injet® AI Teejet® LurmarkDrift-beta®	Drift reduction: DG TeeJet® Turbo TeeJet® Hardi® ISO LD 110 Lurmark® Lo-Drift
Caution	Can lead to poor coverage and control of grass weeds Requires higher spray volumes	Suitable for grass control at recommended pressures Some fine droplets

Volume median diameter (VMD): 50% of the droplets are less than the stated size and 50% greater.

Refer to manufacturer's selection charts, as range of droplet sizes will vary with recommended pressure. Always use the lowest pressure stated to minimise the small droplets.

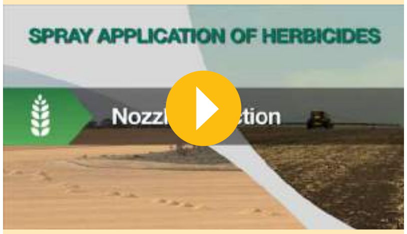
Source: DPI NSW

Spray release height

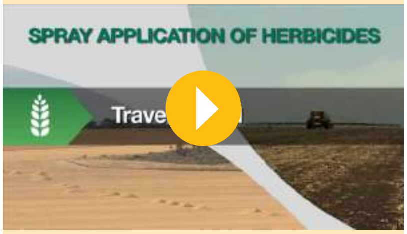
- Operate the boom at the minimum practical height. Drift hazard doubles as nozzle height doubles. If possible, angle nozzles forward 30° to allow lower boom height with double overlap. Lower heights, however, can lead to more striping, as the boom sways and dips below the optimum height.
- 110° nozzles produce a higher percentage of fine droplets than 80° nozzles, but they allow a lower boom height while maintaining the required double overlap.
- Operate within the pressure range recommended by the nozzle manufacturer. Production of driftable fine droplets increases as the operating pressure is increased.

VIDEOS

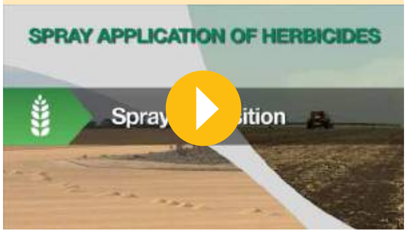
WATCH: Nozzle Selection



WATCH: Travel Speed

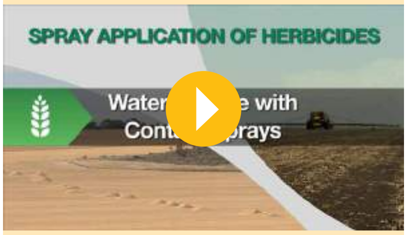


WATCH: Spray deposition

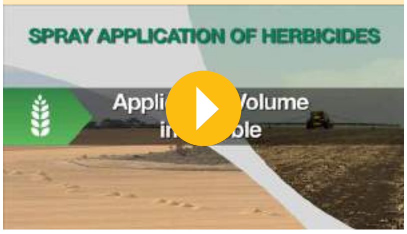


VIDEOS

WATCH: Water volume with contact sprays



WATCH: Application volume in stubble



Size of area treated

When large areas are treated, greater amounts of active herbicide are applied and the risk of off-target effects increases due to the length of time taken to apply the herbicide. Conditions such as temperature, humidity and wind direction may change during spraying.

Application of volatile formulations to large areas increases the chances of vapour drift damage to susceptible crops and pastures.

Capture surface

Targets vary in their ability to collect or capture spray droplets. Well grown, leafy crops are efficient collectors of droplets. Turbulent airflow normally carries spray droplets down into the crop within a very short distance.

Fallow paddocks or seedling crops have poor catching surfaces. Drift hazard is far greater when applying herbicide in these situations or adjacent to these poor capture surfaces.

The type of catching surface between the sprayed area and susceptible crops should always be considered in conjunction with the characteristics of the target area when assessing drift hazard.

Weather conditions to avoid

Turbulence

- Updrafts during the heat of the day cause rapidly shifting wind directions. Spraying should be avoided during this time of day.

Temperature

- Avoid spraying when temperatures exceed 28°C.

Humidity

- Avoid spraying under low relative humidity conditions; i.e. when the difference between wet and dry bulbs exceeds 10°C.
- High humidity extends droplet life and can greatly increase the drift hazard under inversion conditions. This results from the increased life of droplets smaller than 100 microns.

Wind

- Avoid spraying under still conditions.
- Ideal safe wind speed is 3–10 km/h, a light breeze (when leaves and twigs are in constant motion).
- A moderate breeze of 11–14 km/h is suitable for spraying if using low-drift nozzles or higher volume application, say 80–120 L/ha. (Small branches move, dust is raised and loose paper is moving.)

Inversions

The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity. An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, usually less than 50 m thick. Air will not rise above this blanket, and smoke or fine spray droplets and particles of spray deposited within an inversion will float until the inversion breaks down.

Do not spray under inversion conditions.

Inversions usually occur on clear, calm mornings and nights. Windy or turbulent conditions prevent inversion formation. Blankets of fog, dust or smoke and the tendency for sounds and smells to carry long distances indicate inversion conditions.

VIDEOS

WATCH: Advances in weed management—Webinar 2—Spray application in summer fallows

MORE INFORMATION

Surface temperature inversions and spraying factsheet

Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion 'blanket'. [21]

6.9 Potential herbicide damage effect

Herbicide damage causing yield losses in lupin crops has been observed from both residual herbicides applied before cereal crops and from in-crop herbicides. Plants weakened by herbicides are more susceptible to root and foliar diseases such as Phytophthora root rot, Pleiochaeta root rot and brown leaf spot.

6.9.1 GRDC Herbicide Injury Ute Guide

The GRDC Herbicide Injury Ute Guide app is designed to assist in the recognition of injury symptoms caused by herbicides in broadacre winter and summer crops, and in turn assist in reducing crop damage from herbicides in the future. It describes and demonstrates the various types of symptoms that occur, as well as those symptoms caused by each herbicide group.

This information will enable better diagnosis of damage following the application of herbicide. The guide provides information regarding differential diagnosis and factors contributing to crop damage, as well as herbicide drift and off-target damage. A crop may suffer herbicide injury from Improper rate or timing of application; cultivar susceptibility, adverse weather or soil conditions; and/or herbicide drift. Correctly diagnosing the cause of a specific set of symptoms is therefore often difficult. Symptoms of damage to the crop from herbicides do not always mean there will be a loss in grain yield. Recognition of the symptoms of crop injury allows the cause of the injury to be identified and possibly prevented in future crops. [22]

6.9.2 Herbicides that can damage lupins

Lupin is sensitive to group B sulphonamide residues (e.g. Broadstrike®), and be aware of the impact on shallow duplex soils (Photo 3). Sulfonlyureas, imidazolamines and sulfonamides are systemic herbicides that are used for pre and/or post emergent grass and/or broadleaf weed control in cereals and are highly toxic to lupins. Damage can be caused by soil residue or spray contact. Sulfonylurea herbicides, such as Glean® or Logran® applied to preceding cereal crops. Take special note of label instructions concerning crop rotation and plant-back periods, particularly on high pH and/or compacted soils, and after prolonged periods of low rainfall or drought. Metosulam (for example, Eclipse®). Damage can occur in-crop if applied beyond the recommended growth stage. Some varieties are sensitive and have narrow safety margins. Follow label recommendations. Lupin has intermediate sensitivity to the group B imidazolinones (imis, e.g. Spinnaker®, Raptor®, Midas®).

21 A Storrie (2015) Reducing herbicide spray drift. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift

22 GRDC (2017) Herbicide injury ute guide. http://www.uteguides.net.au/UteGuides/Details/bbe07ee9-e187-4cb6-9677-a78a72d45076

MORE INFORMATION

Diagnosing group B herbicide damage in narrow-leaf lupin

Photo 3: *Discoloured leaflets develop brown necrotic spots on the edge and tips then slowly die (left). Seedling lateral roots are severely stunted (right).*

Source: DAFWA

Group C herbicides can cause damage in lupin (Photos 4 and 5). These include root pre-emergent Group C herbicides such as simazine and metribuzin that are routinely used in lupins. Post-emergent atrazine damages lupins. Be aware that application rates vary significantly on different soil types. Follow label recommendations and avoid spray overlaps. Albus lupin is more sensitive to triazine damage. Damage is worse where heavy rain is received prior to crop emergence or when the crop is in the seedling stage.

Photo 4: *Group C herbicide damage in narrow-leaf lupin. Oldest growth is affected first and to a worse degree (left). Plants look pale and stunted in the paddock (right).*

Source: DAFWA

Photo 5: *Albus lupins with simazine (Group C) herbicide damage.*

Photo: T Cook

MORE INFORMATION

[Diagnosing group C herbicide damage in narrow-leafed lupins]

[Tips and tactics – Reducing herbicide damage]

Group I herbicides (Pyridines) interfere with the plant's hormone balance and cell growth. They are primarily absorbed through the foliage but can have some root uptake. All pulses are vulnerable to group I pyridine residues and it can cause serious damage to lupin. [23]

Spray drift from a range of Group I herbicides is a problem in the northern growing region. These herbicides form the basis of most spring/summer knockdown fallow spray applications and poor practice on some properties is leading to spray drift onto sensitive crops. Growers need to consider a range of factors, including weather and their equipment, when applying Group I herbicides, particularly 2,4-D. They should also consider if the product they are using is appropriate and consider alternative herbicides and non-herbicide strategies.

Symptoms can appear within one day of application, with new growth showing distortion in the form of twisting and bending (Photo 6).

23 M Richards (2017) GRDC Update Papers:A pulses update for southern NSW 2017. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/A-pulses-update-for-southern-NSW-2017

MORE INFORMATION

Diagnosing group I herbicide damage in narrow-leafed lupins

Diagnosing group F herbicide damage in narrow-leaf lupin

Diagnosing contact herbicide damage in narrow-leaf lupin

Photo 6: *Upper stems and petioles of plants bend rapidly (left). Drooping plants damaged by herbicide are visible in the paddock (right).*

Source: DAFWA

Group F herbicides (Nicotinanalides; Diflufenican and Picolinofen. Trade names include; Brodal®, Paragon®) can cause damage to lupin crops (Photo 7) and are registered for selective control of wild radish, wild mustard and wild turnip in cereals, legume crops and legume pastures.

Photo 7: *Young growth is worst affected. Bright white or yellow chlorosis that slowly fades can be seen on young leaves.*

Source: DAFWA

6.9.3 Residual herbicides

Pulse growers need to be aware of:

- Possible herbicide residues impacting on crop rotation choices where rainfall has been minimal.
- Herbicide residues could possibly influence crop rotations more than disease considerations.
- Weed burden in the new crop will depend on the seed set from last year.
- Herbicide efficacy and crop safety of the new crop can suffer if the soil is dry at application time.

Herbicide breakdown

Herbicides applied to paddocks in previous years may not have broken down adequately because of insufficient rainfall. Summer rainfall is not necessarily as effective as growing season rainfall in breaking down herbicide residues, so needs to be substantial and to keep the soil wet for a specified time. Read the herbicide label. It will be extremely important to know the chemical type used, as well as the plant-back periods, and the soil pH, rainfall and other requirements for breakdown. Herbicides applied two years ago could still have an impact too, as could the presence of cereal stubble with herbicides like Lontrel®.

Withholding periods for dicamba or similar 'spikes' to knockdown sprays used pre-sowing may need to be longer if there is no rainfall to activate chemical breakdown, otherwise poor establishment can occur. Note that dicamba plant-backs only commence after 15 mm of rain. Alternative products with lesser or no residual may be more appropriate (e.g. carfentrazone-ethyl, oxyfluorfen). In areas that receive minimal summer-autumn rains and delayed opening rains, then the herbicide residual effect becomes far more pressing on rotation choices. Pulse following cereal could then become a higher risk situation than pulse following a pulse. [24]

MORE INFORMATION

Residual herbicides and weed control.

6.9.4 Avoiding herbicide damage

Select a herbicide which is necessary for the weed population you have. Make sure you consider what the recropping limitations may do to future rotation options. Read the herbicide label including the fine print.

Chemical users are required to keep good records, including weather conditions, but in the case of unexpected damage good records can be invaluable, particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock).

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

Be wary of compounding a residue problem by planting a herbicide resistant crop and spraying with more of the same herbicide group. You may get around the problem with residues in the short term, only to be faced with herbicide resistant weeds in the longer term.

Group B: The sulfonylureas (SU's).

The sulfonylureas persist longer in alkaline soils (pH > 7) where they rely on microbial degradation. Residual life within the sulfonylurea family varies widely with chlorsulfuron persisting for 2 or more years and not suitable for highly alkaline soils. Triasulfuron persists for 1–2 years and metsulfuron generally persists for less than 1 year. Legumes and oilseeds are most vulnerable to SU's.

24 Pulse Australia. (2015). Australia Pulse Bulletin: Residual herbicides and weed control. http://www.pulseaus.com.au/growing-pulses/publications/residual-herbicides

Group B: The triazolopyrimidines (sulfonamides).

There is still some debate about the ideal conditions for degradation of these herbicides. However, research in southern Australia has shown that the sulfonamides are less likely to persist than the SU's in alkaline soils. Plant back periods should be increased in shallow soils.

Group B: The imidazolinones (IMI's).

The imidazolinones are very different from the SU's as 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, they can break down very rapidly (within 15 months in alkaline soils), but in heavy clay soils they can persist for several years. Breakdown is by soil microbes. Oilseeds are most at risk. Widespread use of imi-tolerant canola and wheat in recent years has increased the incidence of imidazolinone residues.

Group C: The triazines.

Usage of triazines has increased to counter Group A resistance in ryegrass and because of high rates used on Triazine Tolerant canola. Atrazine persists longer in soil than simazine. Both generally persist longer on high pH soils. Recent research in the US indicates that breakdown rates tend to increase when triazines are used regularly as the number of microbes able to degrade the herbicide can increase. This may mean that breakdown can take an unexpectedly long time in soils that have not been exposed to triazines for some years.

Group I: The phenoxys.

Clopyralid and aminopyralid can be more risky on heavy soils and in conservation cropping as it can accumulate on stubble. Even low rates can cause crop damage up to two years after application. They cause twisting and cupping, particularly for crops suffering from moisture stress.

2,4-D used for fallow weed control in late summer may cause a problem with autumn sown crops. There have been changes to the 2,4-D label recently and not all products can be used for fallow weed control – ensure to check the label.

The label recommends to avoid sowing sensitive crops, until after a significant rainfall event. Oilseeds and legumes are very susceptible to injury from 2,4-D. [25]

MORE INFORMATION

Avoiding crop damage from residual herbicides

6.10 Herbicide resistance

Key points:

Resistance characteristics:

- Resistance remains for many years, until all resistant weed seeds are gone from the soil seed bank
- Resistance evolves more rapidly in paddocks with frequent use of the same herbicide group, especially if no other control options are used.

Action points:

- Assess your level of risk with the online glyphosate resistance toolkit.
- Aim for maximum effectiveness in control tactics, because resistance is unlikely to develop in paddocks with low weed numbers.
- Do not rely on the same MoA group.
- Monitor your weed control regularly.
- Stop the seedset of survivors. [26]

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

26 QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

Overuse of particular groups of herbicides can lead to herbicide resistance, especially in grass weeds. Broad-scale herbicide resistance is continuing to spread through the GRDC Northern Region (Photo 8). Effective grass control in the lupin crop has the benefit of reducing the need for selective grass herbicides in the following cereal year. [27]

Photo 8: *2,4-D resistant radish, Wonga(b)n Hills. (Photo A Storrie,*

Source: GRDC

Survey work in the region has identified over 70 different weed species that impact on grain production and over 10% of these weed species have confirmed populations within Australia that are resistant to glyphosate and several other chemical modes of action (MOA) (Table 10).

Table 9: *Confirmed herbicide resistance in weed populations found in NSW and Queensland.*

Mode of Action	Resistant weeds
A (fops, dims, dens)	wild oats, paradoxa grass, annual ryegrass
B (SUs, imis etc)	annual ryegrass, wild oats, paradoxa grass, Indian hedge mustard, charlock, wild radish, turnip weed, African turnip weed, common sowthistle, black bindweed
C (triazines, ureas, amides etc)	awnless barnyard grass, liverseed grass
D (DNAs, benzamides etc)	annual ryegrass
I (phenoxys, pyridines etc)	wild radish
L (bipyridyls i.e. diquat, paraquat)	flaxleaf fleabane
M (glycines i.e. glyphosate)	annual ryegrass, awnless barnyard grass, liverseed grass, windmill grass, feathertop Rhodes grass, sweet summer grass, flaxleaf fleabane, common sowthistle
Z (dicarboxylic acids etc)	wild oats

Source: adapted from a table prepared by M Widderick, DAF, in WeedSmart

27 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

6.10.1 Why do weeds develop resistance?

Resistant weeds are naturally present in most paddocks in low numbers, even if herbicides have not been applied. Weeds not controlled by a herbicide application are either spray escapes or are naturally resistant survivors. If the resistant weeds set seed, the proportion of resistant weeds in the paddock increases. Resistant weeds will eventually dominate the population if high selection pressure is continued by repeatedly using the same herbicide group (Figure 3). Once a weed population is resistant to a herbicide it is also resistant to other herbicides with the same mode of action. Changing brand names will not control these weeds. Be aware of the mode of action group of the product, and use different chemical modes of action. Multiple resistance (to more than one mode of action) has developed in some weed populations of annual ryegrass and wild radish.

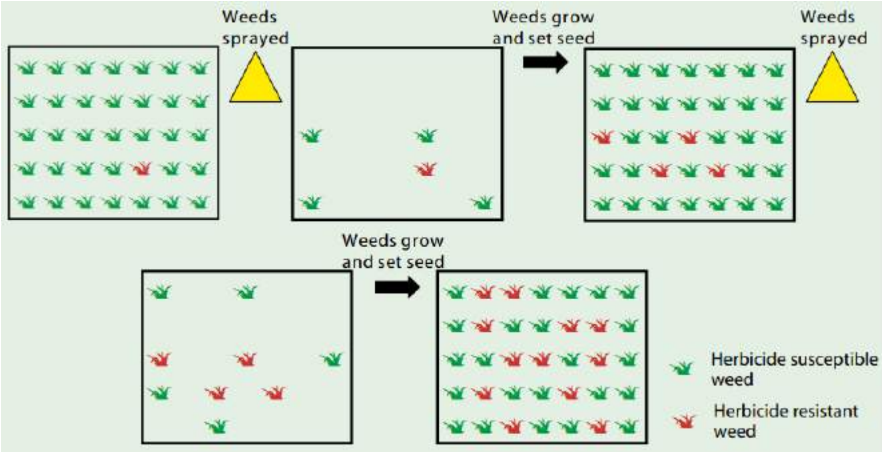


Figure 3: *Resistant weeds are naturally present in most paddocks and can dominate the population if a different herbicide mode of action or another form of weed control is not used to control them.*

Source: NSW DPI

Once resistance has developed in a paddock it will be impossible to totally eradicate all the resistant individuals. It will be necessary to adopt an IWM plan that keeps the numbers of resistant individuals at very low levels in future crops. The rate at which herbicide resistance appears in a population is affected by the selection pressure placed on the population, the initial frequency of the resistance gene and the total number of weeds treated. Resistance may develop in one location under certain conditions but may not develop in another location under similar conditions. [28]

Although growers are making good use of chemical strategies such as double knock, residual herbicides, spot spraying and weed sensing technology to preserve herbicide efficacy, there is an urgent need to investigate non-chemical options that can be added to a weed management program to target resistant weeds in the Northern region.

To avoid herbicide resistance, weed management through the rotation should minimise the need for herbicides. Avoid overuse of any one chemical group, use the least selective herbicide, and avoid the need to spray high weed populations.

6.10.2 Non-herbicide weed control in the Northern region

Diversity in cropping systems and diversity in weeds in the GRDC Northern Region calls for diversity in weed management solutions, which includes the utilisation of non-herbicide tactics.

MORE INFORMATION

Weed control in central-west NSW – Herbicide resistance.

28 A Johnson, N Border, B Thompson, A Storrie (2007) Weed control in central west NSW – Chapter 7: Herbicide resistance. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/154726/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-8.pdf

Weeds researchers recognise that although growers are making good use of chemical strategies such as double-knock, residual herbicides, spot spraying and weed-sensing technology to preserve the efficacy of herbicides for as long as possible, there remains an urgent need to investigate non-chemical options that can be added to a weed management program to target resistant weeds, as outlined in the WeedSmart 10 Point Plan, including rotation diversity, hay/long fallow/brown manure, crop competition and harvest weed seed control.

Strategic tillage

Most growers are keen to preserve their zero- or minimum-till farming systems because they have delivered significant benefits, and are understandably reluctant to re-introduce cultivation to control weeds. Research is under way to investigate ways to use cultivation that will have maximum effect on driving down weed numbers while having least impact on minimum-till farming. The aim of this research is to investigate the impact of different types of tilling where the weed population has blown out and intensive patch or paddock management is required.

For the research team, the key was to understand weed ecology, particularly how seed in the soil seedbank responds to different types of cultivation. The team used small plots to determine the effect of burying weed seeds on their persistence (long-term viability after burial in soil) and emergence. They also experimented to determine the displacement of seed throughout the cultivated zone using four different types of machine compared to a zero-till control.

Sowthistle emergence occurs primarily from seeds close to the soil surface, with up to 30% of viable seeds emerging over five months. Seed can emerge from a depth of up to 2 cm, with approximately 4% emergence after six months. Seed buried below 5 cm is unable to emerge, but still remains viable.

Seed persistence in fleabane was most reduced when seed was buried to 2 cm and let undisturbed for at least two years. Seed buried to a depth of 10 cm remained viable for over three years.

Feathertop Rhodes grass seed persisted for only 12 months regardless of being left on the surface or buried to 10 cm.

Barnyard grass however, persisted on the soil surface for up to two years, and when buried to 10 cm depth remained viable for over three years.

The Gyral machine placed the majority of weed seed in the 0–2 cm and 2–5 cm zones while the offset discs and one-way discs achieving burial of about half the seed below 5 cm depth.

All species responded to increased tilling intensity with reduced germinations. The message from this research is that infrequent but intense cultivation can be a useful weed-management tool within an otherwise zero-till system. Generally, once a paddock has been deeply cultivated there should be no cultivation of that area or paddock for at least four years so as to avoid the risk of bringing seed back to the soil surface.

Strategic burning

Feathertop Rhodes grass is known to colonise around mature plants, and may spread from here to form distinct weedy patches. Once it gets this big, killing the large plant at the centre of the colony is usually not possible using chemical treatments.

In this situation, the strategic burning of early infestations can effectively reduce the biomass of the part of the colony that survives and reduce the amount of viable seed present on the soil surface from 7,500 seeds/m^2 to less than 500 seeds/m^2. Growers have made effective use of a flame-thrower to burn large feathertop Rhodes grass plants during the fallow (Photo 9).

Photo 9: *Strategic burning of feathertop Rhodes grass in a fallow can be an effective way of reducing the biomass of the survivor plant and of reducing the amount of viable seed on the soil surface.*

Source: WeedSmart

MORE INFORMATION

[Non-herbicide weed control in the Northern region](http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/)

Managing herbicide resistance in northern NSW

Crop competition

Using crop competition by planting with a narrower row spacing and or greater planting density provides an effective offensive against common weeds. However, the effect of crop competition on its own, in commercial situations, would have to be used in conjunction with herbicide. [29]

Managing brown and green manure pulse crops in southern NSW

Key points:

- Brown manuring can form part of a strategy to manage herbicide resistance.
- It boosts soil nitrogen while conserving moisture for the next crop.
- Cereal diseases, such as take-all and crown rot, can be reduced through use of break crops.
- The timing of spray application is determined by the target weeds.
- The value of a pulse needs to be considered in the context of the whole rotation.

The practice of green manuring (growing a crop, usually a legume, for its benefits to the soil and to following harvestable crops) is traditional in long-established farming systems, however is not as common in the Northern region. Green manuring can increase both wheat yields and grain protein.

The technique involves growing as much green matter as possible, and either ploughing it in or spraying it with a herbicide during the spring in the year before wheat is sown.

The main differences between green manuring and traditional long fallowing are: that the legume is sown and managed to produce maximum bulk; that grasses are sprayed out to stop any build-up of root disease pathogens; and that green manuring is done relatively late in the season when the legume was at the late flowering stage.

Brown manuring of pulse crops is becoming an increasingly popular tool for weed management, particularly where there is herbicide resistance, and for boosting reserves of soil nitrogen for use by the following crop.

Brown manure cropping involves growing a pulse crop to spray out using a knockdown herbicide to prevent weed seed set and maximise nitrogen fixation. This is different to green manuring, where the crop and weeds are killed by cultivation.

29 WeedSmart (2017) Non-herbicide weed control in the Northern Region. WeedSmart, http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/

There are three key reasons for brown or green manuring pulses: to help manage weeds, particularly if there is herbicide resistance present, to boost soil nitrogen and to conserve soil moisture for subsequent crops.

Brown manuring pulse crops is becoming a more common practice, particularly in southern New South Wales, as cropping intensity increases and the frequency of pastures in rotations declines. Some growers in southern NSW have had difficulty in marketing pulses in recent years or have experienced damage to legume hay. These factors have influenced growers to consider including brown manured crops in a rotation, rather than leaving pulses out altogether.

To use brown manuring for weed control, pulse crops must be desiccated at or before the milky dough stage of the target weeds. This is usually at or before the flat pod stage of the pulse, well before the crop's peak dry matter production. At this stage, the crop is growing at its maximum rate – about 80 to 100 kilograms of DM per hectare per day – and so the amount of nitrogen fixed will be reduced in proportion to its growth stage at desiccation. [30]

MORE INFORMATION

Managing brown manure crops in southern NSW

Brown manuring pulses on acidic soils in southern NSW- is it worth it?

IN FOCUS

Brown manuring pulses on acidic soils in southern NSW – is it worth it?

NSW DPI Pulse team established a series of experiments at Wagga Wagga in southern NSW from 2012–2014 to investigate the effects of pulse crops on the farming system if harvested for grain or brown manured. A range of legume crops were sown in year one at three sowing times and were either brown manured at the stage of black oat anthesis or the crop was taken through to grain harvest. These were followed with two consecutive wheat crops in 2013 and 2014. There are four key messages from this work. Firstly, southern NSW growers will maximise their rotational returns by taking pulse crops through to harvest and selling the grain. Secondly, most pulse crops are likely to provide flow-on benefits to the following wheat crops provided they are well managed. Thirdly, growers should choose the pulse that best fits their farming system – the one easiest to grow and market. Finally, weeds are the major driver for brown manuring in southern NSW. [31]

6.10.3 Weed seed in grain samples

Many growers may unknowingly introduce significant levels of weed and volunteer crop seeds into the farming system at seeding time, even when crop seed has been cleaned. Many of these weed seed populations are resistant to a range of commonly used post-emergent herbicides.

Uncleaned crop seed samples can have almost 25 times more contamination than cleaned crop seed. It is important to remember that resistance will evolve faster from introducing resistant weed seeds into a paddock, compared to resistance evolving independently in that paddock.

The cleaning method used strongly influences contamination levels – a 'gravity table' is the most effective, followed by other methods such as rotary screens and sieves.

30 GRDC. (2013). Managing brown manure crops in southern NSW – Factsheet.

31 E Amrstrong, G O'Connor, L Gaynor, S Ellis, N Coombes. (2015). Brown manuring pulses on acidic soils in southern NSW- is it worth it? Proceedings of the 17th ASA Conference, 20 – 24 September 2015, Hobart, Australia. http://www.agronomy2015.com.au/1173

Crop type also has a significant effect on the amount of contamination, with wheat containing much higher annual ryegrass seed numbers than barley, possibly because barley was more likely to out-compete weeds during the growing season.

Retained grain can be contaminated with weed seeds if seed cleaning methods are only partially effective. Introducing contaminated crop seeds into cropping paddocks could impact on future management options in addition to reduced yields and increased herbicide costs. Sowing clean seed is important to minimise the introduction of weed seeds and also helps reduce the introduction of weed species or herbicide-resistant biotypes. [32]

Receival standards

Lupin receival standards stipulate that no more than 2% (4 g) by weight of a sample can be contaminated with weed seed of Ryegrass, Canary seed, Turnip, Canola, Dock seed, Radish seed.

There are also restrictions on weed seed according to the 200 g count (Table 10).

Table 10: *Lupin weed seed receival standards 2016/2017 – 200 g count.*

Weed	Max seed count
Sunflower, Safflower, Variegated Thistle.	1
Saffron thistle	3
Doublegees/spiny emex	8
Bitter lupin	2
Yellow lupin	30

Source: CBH

Seed cleaning methods

Using a gravity table to clean seed is the best method as it leads to the lowest levels of weed seed contamination in grain samples across all crop types.

A rotary screen and a combination of more than one cleaning method are the next most effective methods, followed by sieves. Cleaning by external contractors produced better results than self-cleaning by growers. [33]

6.10.4 Ten-point plan to weed out herbicide resistance

WeedSmart has developed a 10-point plan that farmers can use to protect the longevity of chemicals and slow down the development of resistance. [34]

1. Act now to stop weed seedset

Creating a plan of action is an important first step in integrated weed management.

- Destroy or capture weed seeds.
- Understand the biology of the weeds present.
- Remember that every successful weed-smart practice can reduce the weed seedbank over time.
- Be strategic and committed: herbicide resistance management is not a one-year decision.
- Research and plan a weed-smart strategy.
- Growers may have to sacrifice yield in the short term to manage resistance: be proactive.

MORE INFORMATION

Weed smart – clean seed

Consider clean seed and herbicide resistance testing for retained seed

Strategic risk management

Farm business management: making effective business decisions

VIDEOS

WATCH: Act now: Plan your weed management program

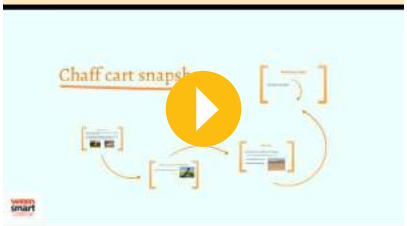
32 WeedSmart. Clean seed. https://weedsmart.org.au/clean-seed/

33 GRDC (2013) Consider clean seed and herbicide resistance testing for retained seed. https://grdc.com.au/news-and-media/news-and-media-releases/west/2013/12/consider-clean-seed-and-herbicide-resistance-testing-for-retained-grain

34 WeedSmart. Ten-point plan. WeedSmart, https://weedsmart.org.au/the-big-6//

VIDEOS

WATCH: Chaff carts 101



WATCH: Capture weed seeds at harvest: Harrington seed destructor

WATCH: Strategic narrow windrow burning

WATCH: The art of narrow windrow burning

WATCH: Chaff funneling onto tramlines

2. Capture weed seeds at harvest

Destroying or capturing weed seeds at harvest is the number one strategy for combating herbicide resistance and driving down the weed seedbank. There are several ways to do this:

- Create and burn narrow windrows. (Photo 10)
- Use a Harrington Seed Destructor or other intergrated seed destructor (Photo 11). [35]
- Produce hay where suitable.
- Funnel seed onto tramlines in controlled-traffic farming (CTF) systems.
- Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.
- Tow a chaff cart behind the header.

Photo 10: *Narrow windrow burning the Northern region.*

Photo: P Heuston

Controlling weed seeds at harvest is emerging as the key to managing the increasing levels of herbicide resistance, which is putting Australia's no-till farming system at risk.

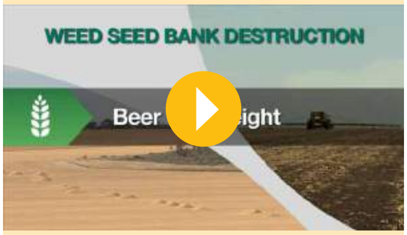
Lupin is well suited to harvest weed seed control tactics, such as narrow windrow burning, chaff cart, Harrington seed destructor, where weed seed is concentrated in the chaff stream at harvest.

35 A Roginski (2012) Seed destructor shows its national potential. Ground Cover. No. 100. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-issue-100/Seed-destructor-shows-its-national-potential

VIDEOS

WATCH: Capture weed seeds at harvest: Bale Direct System

WATCH: IWM: Weed seed vdestruction—Beer can height



WATCH: Crop rotation with Colin McAlpine

WATCH: Test for resistance to establish a clear picture of paddock-by-paddock farm status

Photo 11: *Harrington weed-seed destructor at work in the paddock.*

Source: GRDC

For information on harvest weed-seed control and its application, see Section 12: Harvest.

3. Rotate crops and herbicide modes of action

Crop rotation is beneficial to farming systems. Make sure weed management is part of the decision when planning crop rotation. Crop rotation offers many opportunities to use different weed control tactics, both herbicide and non-herbicide, against different weeds at different times. Rotating crops also gives farmers a range of intervention opportunities. For example, growers can; crop-top lupins and other pulses, windrow canola, and delay sowing some crops.

Rotations that include both broadleaf crops (e.g. pulses and oilseeds) and cereals allow the use of a wider range of tactics and chemistry.

Growers also have the option of rotating to non-crop options, e.g. pastures and fallows.

Within the rotation it is also important to not repeatedly use herbicides from the same MOA group. Some crops have fewer registered-herbicide options than others, so this needs to be considered too, along with the opportunities to use other tactics, such as the control of harvest weed seed, in place of one or more herbicide applications.

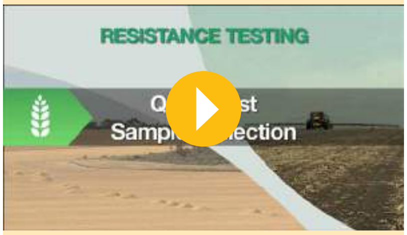
4. Test for resistance to establish a clear picture of paddock-by-paddock status

- Before harvest, sample weed seeds and resistance test to determine effective herbicide options. One such service is provided by Plant Science Consulting.
- Use the 'quick test' option to test emerged ryegrass plants after sowing to determine effective herbicide options before applying in-crop selective herbicides.
- Collaborate with researchers by collecting weeds for surveys
- Visit WeedSmart for more information on herbicide-resistance survey results.

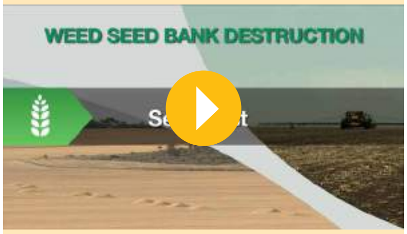
It is clearly too late to prevent the evolution of resistance to many common herbicides. However, a resistance test when something new is observed on the farm can be very useful in developing a plan to contain the problem, and in developing new strategies to prevent this resistance evolving further.

VIDEOS

WATCH: IWM: Resistance Testing—'Quick-Test' sample collection



WATCH: IWM: Seed test—What's involved



WATCH: Don't cut the rate

WATCH: Don't automatically reach for glyphosate

WATCH: Manage spray drift

Perhaps the best use for herbicide-resistance tests is to use them to determine if a patch of surviving weeds are worse than what the grower has observed before. Take a GPS recording of the site location of potentially resistant weeds. These weeds may give insight into the future resistance profile of the farm if it is not contained and resistance testing in these situations can be very useful in building preventative strategies.

5. Never cut the rate

The Australian Herbicide Resistance Initiative (AHRI) has found that ryegrass being sprayed at below the advised rate of Sakura® evolved resistance not only to Sakura® but to Boxer Gold® and Avadex® too. To avoid this problem occurring:

- Use best management practice in spray application: apply according to the directions on the label.
- Consider selective weed sprayers.

6. Don't automatically reach for glyphosate

Glyphosate has long been regarded as the world's most important herbicide, so it's natural to reach for it at the first sign of weeds. Resistance to this herbicide is increasing rapidly, and in some areas it may fail completely. This can be due to too much reliance on one herbicide group, giving the weed opportunity to evolve resistance.

Instead, introduce paraquat products when dealing with smaller weeds, and for a long-term solution farm with a very low seedbank. Also:

- Use a diversified approach to weed management.
- Consider post-emergent herbicides where suitable.
- Consider strategic tillage.

7. Carefully manage spray events

It's important to set up spray gear to maximise the amount of herbicide that directly hits the target. This makes the spray application more cost-effective by killing the maximum number of weeds possible, and it also protects other crops and pastures from potential damage and/or contamination.

Spray technology has improved enormously in the last 10 years, making it far easier for growers to get herbicides precisely where they need to be. Also, many herbicide labels specify the droplet spectrum to be used when applying the herbicide.

As a general rule, medium to coarse droplet size combined with higher application volumes provides better coverage of the target. Using a pre-orifice nozzle slows droplet speed so that droplets are less prone to bouncing off the target.

Using oil-based adjuvants with air-induction nozzles can reduce herbicide deposition by reducing the amount of air in the droplets. These droplets then fail to shatter when they hit the target, which increases droplet bounce.

- Stop resistant weeds from returning into the farming system.
- Focus on management of survivors in fallows.
- Where herbicide failures occur, do not let the weeds seed. Consider cutting for hay or silage, fallowing or brown manuring the paddock.
- Patch-spray areas of resistant weeds only if appropriate.

8. Plant clean seed into clean paddocks with clean borders

With herbicide resistance on the rise, planting clean seed into clean paddocks with clean borders has become a top priority. Controlling weeds is easiest before the crop is planted, so once that is done plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant ones.

Introducing systems that increase farm hygiene will also prevent new weed species and resistant weeds. These systems could include crop rotations, reducing weed

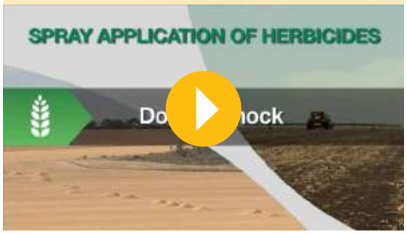
VIDEOS

WATCH: Plant clean seed into clean paddocks with clean borders

WATCH: Best results with double-knock tactic

WATCH: Double-knock application—a grower's experience

WATCH: Spray application of herbicides—Double-knock



burdens in paddocks or a harvest weed-seed control such as the Harrington Seed Destructor or windrow burning.

Lastly, roadsides and fence lines are often a source of weed infestations. Weeds here set enormous amounts of seed because they have little competition, so it's important to control these initial populations by keeping clean borders.

- It is easier to control weeds before the crop is planted.
- Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
- An 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

The benefits of the double-knock technique is in combining two weed-control tactics with different modes of action, on a single flush of weeds. These two 'knocks' happen sequentially, with the second application being designed to control any survivors from the first.

One such strategy is the glyphosate–paraquat double-knock. These two herbicides use different MOAs to eliminate weeds and so make an effective team when paired. When using this combination ensure the paraquat rate is high. The best time to initiate this double-knock is after rainfall. New weeds will quickly begin to germinate and should be tackled at this small stage.

10. Employ crop competitiveness to combat weeds

There are numerous ways that growers can increase the competitive ability of crops against weeds:

- Consider narrow row spacing and increasing seeding rates.
- Consider twin-row seeding points.
- Consider east-west crop orientation.
- Use varieties that tiller well.
- Use high-density pastures as a rotation option.
- Consider brown-manure crops.
- Rethink bare fallows.

6.10.5 If resistant weeds are suspected

As soon as resistance is suspected, growers should contact their local agronomist. The following steps are then recommended.

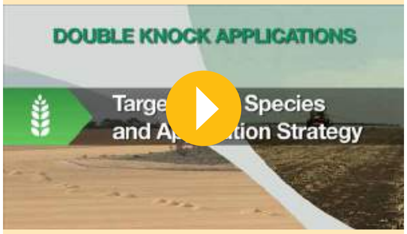
First, consider the possibility of other common causes of herbicide failure by asking:

- Was the herbicide applied in conditions and at a rate that should kill the target weed?
- Did the suspect plants miss herbicide contact or emerge after the herbicide was applied?
- Does the pattern of surviving plants suggest a spray miss or other application problem?
- Has the same herbicide or herbicides with the same MOA been used in the same field or in the general area for several years?
- Has the uncontrolled species been successfully controlled in the past by the herbicide in question or by the current treatment?
- Has a decline in the control been noticed in recent years?
- Is the level of weed control generally good on the other susceptible species?

If resistance is still suspected:

VIDEOS

WATCH: [Double knock applications: target weed species and application strategy]



WATCH: [Learn to think outside the drum]

WATCH: [Crop competition—Increasing wheat seeding rate]

WATCH: [Crop competition—Row spacing]

- Contact crop and food-science researchers in your state agricultural department for advice on sampling suspect plants for testing of resistance status..
- Ensure all suspect plants do not set seed.
- If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread. [36]

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
  Phone (02) 6933 4001
- Charles Sturt University's Graham Centre weed research group
- Plant Science Consulting
  22 Linley Avenue, Prospect
  SA 5082
  email: info@plantscienceconsulting.com.au
  Phone: 0400 664 460

MORE INFORMATION

CropLife Australia

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

Cotton Info, Weed pack

Managing herbicide resistance in Northern NSW

36 DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

Insect control

Key messages

- Insects can cause serious damage to lupins during pod and seed development. Insect management during pod fill is critical to produce export quality albus lupins.
- Integrated Pest Management strategies can be effective in controlling insect pests while reducing reliance on chemical control and help to limit pesticide resistance.
- Earth mites, aphids and caterpillars can cause serious damage to lupins. Snails and slugs can also lead to major yield losses.
- Take time to consider relevant withholding periods before applying chemical control.
- For current chemical control options refer to the Pest Genie or Australian Pesticides and Veterinary Medical Authority.

Lupin crops are more prone to insect damage than cereal crops and need to be checked at critical periods for insects (Tables 1 and 2).

In the three weeks following emergence, Red legged earth mite, cutworm and Lucerne flea can cause damage to lupin plants. Aphids, mirids and thrips can become a problem during flowering. Caterpillars (in particular lucerne seed web moth and Helicoverpa) can cause significant yield losses in lupin, especially during during pod fill. [1] They eat their way through the walls of the young pods and feed on the developing seeds. Very young pods may abort. Seeds suffer physical damage that affects the quality of the harvested seed. It also affects the germination percentage of the sowing seed for the following year. [2]

Table 1: *Insect pests that can cause damage to lupin crops in the Northern region.*

Insect	Threshold	Crop growth stage	Crop damage	Comments	Frequency
Aphids	Treat at first sign of virus infected plants or appearance of aphid clusters on flowering spikes.	Late vegetative, budding and flowering	Reduce pod set and transmit viruses. Cause stunted plants.	Eliminate weeds such as hexham scent, fumitory and stagger weed. Retained cereal stubble repels aphids from crop. Treatment of aphids has not always prevented virus transmission.	Intermittent
Armyworms	Usually present in large numbers. Most active in afternoon/ night.	Pod filling	Chew off pods which drop on ground.	Rarely a problem in lupins. Prefer winter cereals, especially barley. Buildup often occurs after heavy rain.	Rarely

1 I Pritchard (2015) Lupin essentials – growing a successful lupin crop. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4

2 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Insect	Threshold	Crop growth stage	Crop damage	Comments	Frequency
Blue Oat Mites and Redlegged Earth Mites	Check seedlings for presence of mites after the autumn break. Spray if growth is retarded.	Seedling emergence to 4 leaf stage. Look for damage to cotyledons. Can kill seedling.	Mottle and whiten cotyledons and leaves by rasping and sucking. May stunt and kill seedlings. RLEM more common in southern NSW.	Most feeding during cooler part of day/ night. Often present under clods or underside of weeds such as capeweed/ saffron thistle during day.	Annual
Cutworms	Usually in large numbers in patches in a crop. Treat at first sign of damage preferably in late afternoon	Early plant growth stages.	Eat leaves and cut stems at or below ground level. Remain in soil during the day.	Inspect crop late afternoon or night for presence of large dark grey-green caterpillars. Over the row band spraying (night) or spot treatment.	Rarely
Helicoverpa caterpillars	Depends on value of lupins and stage of pod filling. Albus lupins more susceptible. 1–2 larvae per m^2 less than 5 mm long for human consumption. 1–2 larvae per 10 sweeps for stock feed.	Can cause flower and pod abortion at early flowering. More commonly present late flowering and pod filling.	Small caterpillars feed inside flowers (1–5 mm). Large caterpillars (25 mm) eat holes in pods and seeds.	Examine crops weekly during flowering. Seed for stock feed can tolerate some damage. H. punctigera most common in spring. H. armigera in low numbers within 30 km of summer irrigation.	Annual
Loopers	Rarely a problem in lupins. Move in from edge of crop.	Early plant growth stages.	Defoliate plants.	Capeweed is the preferred host. Caterpillars have a distinct looping motion.	Rarely
Lucerne fleas	Control may be necessary in southern NSW. Spray if seedling leaf area is likely to be reduced by 50%	Seedling up to 4 leaf stage. Crop on heavy acidic soils most prone to damage	Eat leaves, leaving clear membranous windows in foliage.	Eliminate weeds on headlands. Lucerne fleas hop when disturbed. Liming reduces flea numbers on acidic soils.	Intermittent
Lucerne seed web moths	At the first sign of damage. Treatments for heliothis will give some control.	Flowering and podding	Small caterpillars bore into seeds, leave webbing and excrement on pods.	Attack may go unnoticed until damage has occurred. No recommended control measure.	Rarely
Thrips	A sporadic pest in lupins, it is good practice to monitor for them each year. Check for presence in flowers. 1–2 thrips per flower.	Budding and flowering.	Reduce flowering and cause pod abortions.	Shake flowers into white container to dislodge thrips or open and inspect flowers.	Sporadic

Source: NSW DPI

Table 2: *Insect pest risk according to conditions.*

High risk	Moderate risk	Low risk
Establishment pests		
History of high mite pressure. Previous crop hosts of earth mite populations e.g. pastures. Cool, dry or wet conditions that result in slow crop emergence and seedling growth. Weedy crop and/or crop edges hosting RLEM that may move into germinating crop. Yellow lupin (e.g. Wodjil) is very susceptible to damage by RLEM	Following a crop with reduced hosting capacity for RLEM e.g. faba bean, narrow-leafed lupin and lentils.	Following a crop in which RLEM reproduction is low, or where RLEM have been controlled in prior to summer diapause e.g. chickpeas, winter cereal, albus lupins. Rapid emergence and establishment of seedlings.
Native budworm		
Wet winters in breeding areas of central Australia + suitable weather conditions that bring moths from west to east result in spring migrations. Repeated influxes of moths over long periods, resulting in need for continuous monitoring and potentially repeat infestations.	Broadleaf weeds hosting cutworm and helicoverpa that move into the crop as large, damaging larvae. Hot weather in spring can cause small larvae to burrow into pods. Wet harvest weather results in pods that are 'softer' for longer and susceptible to damage right up to harvest. High beneficial insect activity	Dry winters in breeding areas low source population absence of frontal wind systems that provide opportunities for migration.
Aphids and virus		
Present in both low and high rainfall areas and irrigation districts. Proximity of crop to 'green bridge' e.g. lucerne, medics, clover, volunteer pulses and broadleaf weeds – potential source of aphids and virus.	Wet autumn and spring promotes the growth of weed hosts – when weed hosts dry off aphids move into crops. Sowing into standing stubble reduces aphid landing. Seed dressings may provide some benefit if protecting against persistent viruses. Rapidly closing canopy that 'shades' out unthrifty, virus infected plants – limits further transmission.	Sowing virus resistant cultivars and certified virus-free seed. Early sowing allows flowering before aphid populations peak

High risk	Moderate risk	Low risk
Slugs and snails		
Annual rainfall >500 mm Above average spring – autumn rainfall No till stubble retained Previous paddock history of slugs and snails Summer volunteers and weeds No sheep in enterprise	450–500 mm annual rainfall Tillage or burnt only Sheep on stubble	<450 mm annual rainfall Drought Tillage and burnt stubbles No volunteers and weeds
Other pests		
Lupins adjacent to pastures may have more problems with pests encroaching across fence lines e.g. such as brown pasture looper and weevils. Narrow leaf lupin varieties Yorrel and Tallerack susceptible to aphid feeding damage.	Wet autumn and spring promotes the growth of weed hosts – when weed hosts dry off pests move into crops.	Narrow leaf lupin varieties Tanjil and Mandelup⦻ are tolerant to aphid feeding damage, but can still be vulnerable to viruses spread by aphids.

Source: IPM Guidelines

7.1 Insect sampling methods

Monitoring for insects is an essential part of successful IPMs and crop growth. Correct identification of immature and adult stages of both pests and beneficials, and accurate assessment of their presence in the field at various crop stages will ensure appropriate and timely management decisions. Good monitoring procedure involves not just a knowledge of and the ability to identify the insects present, but also good sampling and recording techniques and a healthy dose of common sense.

Factors that contribute to quality monitoring:

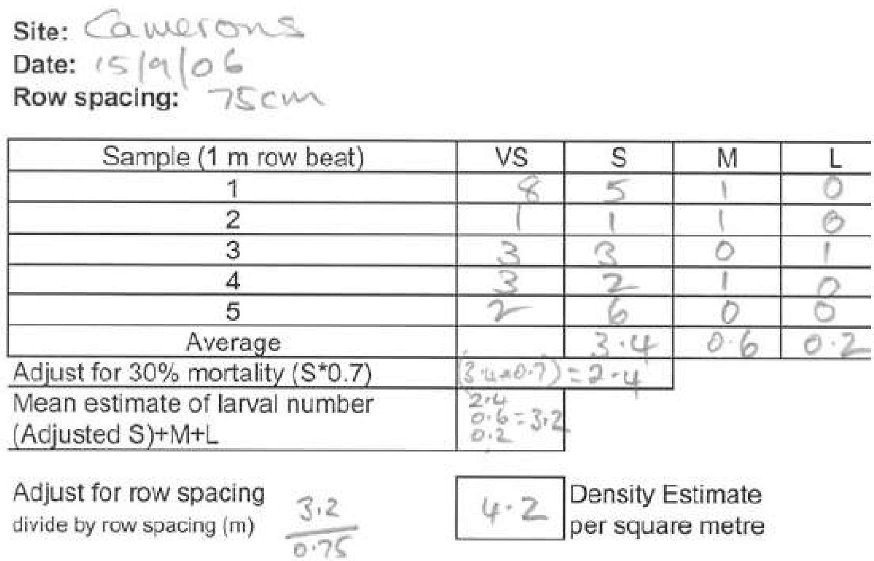
- Knowledge of likely pests/beneficials and their life cycles is essential when planning your monitoring program. As well as visual identification, you need to know where on the plant to look and what is the best time of day to get a representative sample.
- Monitoring frequency and pest focus should be directed at crop stages likely to incur economic damage. Critical stages may include seedling emergence and flowering/grain formation.
- Sampling technique is important to ensure a representative portion of the crop has been monitored since pest activity is often patchy. Having defined sampling parameters (e.g. number of samples per paddock and number of leaves per sample) helps sampling consistency. Actual sampling technique including sample size and number, will depend on crop type, age and paddock size, and is often a compromise between the ideal number and location of samples and what is practical regarding time constraints and distance covered.
- Balancing random sampling with areas of obvious damage is a matter of common sense. Random sampling aims to give a good overall picture of what is happening in the field, but any obvious hotspots should also be investigated. The relative proportion of hotspots in a field must be kept in perspective with less heavily infested areas.

Keeping good records

Accurately recording the results of sampling is critical for good decision making and being able to review the success of control measures (Figure 1). Monitoring record sheets should show the following:

- numbers and types of insects found (including details of adults and immature stages)
- size of insects—this is particularly important for larvae
- date and time
- crop stage and any other relevant information (e.g. row spacings, weather conditions, and general crop observations).

Consider putting the data collected into a visual form that enables you to see trends in pest numbers and plant condition over time. Being able to see whether an insect population is increasing, static or decreasing can be useful in deciding whether an insecticide treatment may be required, and if a treatment has been effective. If you have trouble identifying damage or insects present, keep samples or take photographs for later reference.



Site: Camerons
Date: 15/9/06
Row spacing: 75cm

Sample (1 m row beat)	VS	S	M	L
1	8	5	1	0
2	1	1	1	0
3	3	3	0	1
4	3	2	1	0
5	2	6	0	0
Average		3.4	0.6	0.2
Adjust for 30% mortality (S*0.7)	(3.4×0.7) = 2.4			
Mean estimate of larval number (Adjusted S)+M+L	2.4 0.6 0.2 = 3.2			

Adjust for row spacing
divide by row spacing (m) $\frac{3.2}{0.75}$

4.2 Density Estimate per square metre

Figure 1: *An example of a field check sheet for crops, showing adjustments for field mortality and row spacings.*

Source: QDAF

Records of spray operations should include:

- date and time of day
- conditions (wind speed, wind direction, temperature, presence of dew and humidity)
- product(s) used (including any additives)
- amount of product(s) and volume applied per hectare
- method of application including nozzle types and spray pressure
- any other relevant details.

Sampling methods

Beat sheet

A beat sheet is the main tool used to sample row crops for pests and beneficial insects (Photo 2). Beat sheets are particularly effective for sampling caterpillars, bugs, aphids and mites. A standard beat sheet is made from yellow or white tarpaulin material with heavy dowel on each end. Beat sheets are generally between 1.3–1.5

m wide by 1.5-–2.0 m deep (the larger dimensions are preferred for taller crops). The extra width on each side catches insects thrown out sideways when sampling and the sheet´s depth allows it to be draped over the adjacent plant row. This prevents insects being flung through or escaping through this row.

How to use the beat sheet:

- Place the beat sheet with one edge at the base of plants in the row to be sampled.
- Drape the other end of the beat sheet over the adjacent row. This may be difficult in crops with wide row spacing (one metre or more) and in this case spread the sheet across the inter-row space and up against the base of the next row.
- Using a one-metre stick, shake the plants in the sample row vigorously in the direction of the beat sheet 5–10 times. This will dislodge the insects from the sample row onto the beat sheet.
- Reducing the number of beat sheet shakes per site greatly reduces sampling precision. The use of smaller beat sheets, such as small fertiliser bags, reduces sampling efficiency by as much as 50%.
- Use the datasheets to record type, number and size of insects found on the beat sheet.
- One beat does not equal one sample. The standard sample unit is five non-consecutive one-metre long lengths of row, taken within a 20 m radius; i.e. 5 beats = 1 sample unit. This should be repeated at six locations in the field (i.e. 30 beats per field).
- The more samples that are taken, the more accurate is the assessment of pest activity, particularly for pests that are patchily distributed such as pod-sucking bug nymphs.

When to use the beat sheet:

- Crops should be checked weekly during the vegetative stage and twice weekly from the start of budding onwards.
- Caterpillar pests are not mobile within the canopy, and checking at any time of the day should report similar numbers.
- Pod-sucking bugs, particularly green vegetable bugs, often bask on the top of the canopy during the early morning and are more easily seen at this time.
- Some pod-sucking bugs, such as brown bean bugs, are more flighty in the middle of the day and therefore more difficult to detect when beat sheet sampling. Other insects (e.g. mirid adults) are flighty no matter what time of day they are sampled so it is important to count them first.
- In very windy weather, bean bugs, mirids and other small insects are likely to be blown off the beat sheet.
- Using the beat sheet to determine insect numbers is difficult when the field and plants are wet.

While the recommended method for sampling most insects is the beat sheet, visual checking in buds and terminal structures may also be needed to supplement beat sheet counts of larvae and other more minor pests. Visual sampling will also assist in finding eggs of pests and beneficial insects.

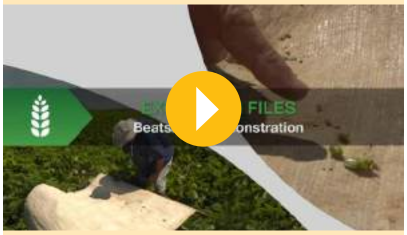
Most thresholds are expressed as pests per square metre (pests/m^2). Hence, insect counts in crops with row spacing less than one metre must be converted to pests/m^2. To do this, divide the 'average insect count per row metre' across all sites by the row spacing in metres. For example, in a crop with 0.75 m (75 cm) row spacing, divide the average pest counts by 0.75.

Other sampling methods:

- Visual checking is not recommended as the sole form of insect checking; however it has an important support role. Leaflets or flowers should be separated when looking for eggs or small larvae, and leaves checked for the

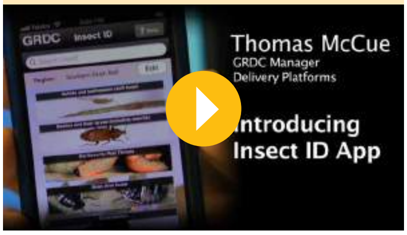
VIDEOS

WATCH: GCTV16: Extension files—IPM beat sheet demo



WATCH: How to use a sweep net to sample for insect pests

WATCH: GCTV11: GRDC's Insect ID App



MORE INFORMATION

IPM guidelines for monitoring tools and techniques.

IPM Guidelines website.

presence of aphids and silverleaf whitefly. If required, dig below the soil surface to assess soil insect activity. Visual checking of plants in a crop is also important for estimating how the crop is going in terms of average growth stage, pod retention and other agronomic factors.

- Sweep net sampling is less efficient than beat sheet sampling and can underestimate the abundance of pest insects present in the crop. Sweep netting can be used for flighty insects and is the easiest method for sampling mirids in broadacre crops or crops with narrow row spacing (Figure 2). It is also useful if the field is wet. Sweep netting works best for smaller pests found in the tops of smaller crops (e.g. mirids in mungbeans), is less efficient against larger pests such as pod-sucking bugs, and it is not practical in tall crops with a dense canopy such as coastal or irrigated soybeans. At least 20 sweeps must be taken along a single 20 m row.
- Suction sampling is a quick and relatively easy way to sample for mirids. Its main drawbacks are unacceptably low sampling efficiency, a propensity to suck up flowers and bees, noisy operation, and high purchase cost of the suction machine.
- Monitoring with traps (pheromone, volatile, and light traps) can provide general evidence on pest activity and the timing of peak egg lay events for some species. However, it is no substitute for in-field monitoring of actual pest and beneficial numbers. [3]

Photo 1: *Sweep netting for insects (left) and use of a beat sheet (right).*

Source: DAFWA and The Beatsheet

For pest identification see the A-Z pest list or consult the GRDC Insect ID: The Ute Guide.

The Insect ID: The Ute Guide is a comprehensive reference guide for insect pests commonly affecting broadacre crops and growers across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored and other pests that they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [4]

App features:

- Region selection
- Predictive search by common and scientific names
- Compare photos of insects side by side with insects in the app
- Identify beneficial predators and parasites of insect pests
- Opt to download content updates in-app to ensure you are aware of the latest pests affecting crops for each region
- Ensure awareness of international bio-security pests

3 QDAF (2012) Insect monitoring techniques for field crops. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/insect-monitoring

4 GRDC, https://grdc.com.au/Resources/Apps

MORE INFORMATION

GrowNotes Alert™

PestFacts south-eastern

Integrated Pest Management Factsheet

Chemical control

Cultural control

Biological control

NSW DPI – Insect and mite control in field crops

VIDEOS

WATCH: GCTV2: Integrated pest management

WATCH: Integrated pest management and pest suppressive landscapes with Phil Bowden

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

7.1.1 GrowNotes Alert™

GrowNotes Alert is a free nationwide system for delivering urgent, actionable and economically important pest, disease weed and biosecurity issues directly to you, the grower, adviser and industry body, the way you want. Real-time information from experts across Australia, to help growers increase profitability.

A GrowNotes Alert notification can be delivered via SMS, email, web portal or via the iOS App. There are also three by dedicated regional Twitter handles – @GNAlertNorth, @GNAlertSouth and @GNAlertWest – that can also be followed.

The urgency with which alerts are delivered can help reduce the impact of disease, pest and weed costs. GrowNotes Alert improves the relevance, reliability, speed and coverage of notifications on the incidence, prevalence and distribution of these issues within all Australian grain growing regions.

7.1.2 Cesar PestFacts

PestFacts (south-eastern) is a free email service designed to keep growers and farm advisers informed about invertebrate issues – and solutions – as they emerge during the winter growing season. The service has a focus on pests of broadacre grain crops.

PestFacts map is an interactive tool that allows users to search and view historical pest reports across Victoria and NSW. The map is updated with each issue of PestFacts to include new reports.

7.2 Integrated Pest Management

Key points:

- Long-term use of broad-spectrum pesticides for invertebrate pest control is not sustainable.
- IPM integrates cultural, biological, chemical controls – where possible, choice of control(s) is based on economic thresholds.
- An understanding of pest and beneficial insect dynamics, and how to monitor them, is essential for successful IPM.
- Reducing reliance on broad spectrum pesticides improves triple bottom line outcomes (economic, environmental and social).

Integrated pest management (IPM) reduces reliance on pesticides, especially broad-spectrum pesticides, limiting the opportunity for resistance and promoting populations of beneficial species.

The fundamental principles of IPM includes:

1. Know the enemy
2. Know the control thresholds for pests according to crop type
3. Monitor populations
4. Select appropriate control methods, giving consideration to Biological and Cultural control options.

The presence of a pest in a crop is not an automatic trigger for control. Attempting to prevent all damage is usually uneconomic. Economic thresholds help to rationalise the use of pesticides and are one of the keys to profitable pest management. The development of economic thresholds requires knowledge of pests, their damage, the crop's response to damage, and estimates of likely crop value and costs of control.

7.2.1 IPM Guidelines for lupin

The following information and strategies are recommended to for Integrated Pest Management in lupins.

- Economic damage is most likely to occur during establishment and from flowering until maturity.
- Lupins can compensate for early and moderate damage by setting new buds and pods to replace those damaged by pests.
- Excessive early damage can reduce yield and delay harvest.
- Narrow-leafed lupin crops will not be damaged by native budworm until they are close to maturity.
- Pod walls are not penetrated until the caterpillars are over 15 mm in length.
- The decision to spray should not be made until caterpillars are greater than 15 mm and pods are losing their green colour.
- Waiting until near the critical growth stage for damage often allows beneficial insects to reduce native budworm numbers below economically damaging levels.
- Where there is a risk of virus transmission by aphids – refer to management options in insects as virus vectors. [5]

7.2.2 Healthy crops are less prone to insect damage

The overall health and vigour of a crop will influence its susceptibility to insect attack, and its ability to compensate for insect damage. Below are some of the crop production factors that can affect plant-insect interactions.

Crop rotations

- Some crop rotations can result in a greater incidence of pests for the subsequent crop, especially soil insects and seedling pests such as mites. Check specific crops for more details.
- Crops sown in paddocks previously containing long term pastures are particularly susceptible to pasture pests (e.g. mites, lucerne flea, and soil insects).
- Rotations may also assist with weed management, reducing the potential for green bridges.

Choice and variety of crop

- Choose a variety with inherited disease and pest resistance where agronomically and economically viable
- Seedling vigour and other physiological features such as hard seed coats will help to deter pests.

Soil preparation

- Cultivation or herbicide use during a fallow to eliminate weeds will minimise pest survival opportunities.

Optimum sowing time

- Select planting windows to minimise the likelihood of major pests during critical development phases of the crop. If possible, avoid staggered plantings in adjacent fields to minimise the opportunity for pests to move between fields as the crop develops.

Successful crop establishment

- Quick uniform establishment improves a crop's ability to withstand insect (and pathogen) attack.
- Seedlings suffering from stresses (moisture, temperature or water logging) are often more susceptible to pests

5 IPM Guidelines (2016) Lupins. http://ipmguidelinesforgrains.com.au/crops/winter-pulses/lupins/

- Appropriate rates of treated seed (seed dressings) may suppress soil insects as well as aphids in the first three weeks

Irrigation

- Drought stressed crops are more susceptible to damage and yield penalties.
- Stressed crops are less able to compensate for damage

Nutrition

- High nitrogen levels in plant tissue can decrease resistance and increase susceptibility to pest attacks (particularly sap-sucking pests), however more research is needed to clarify the relationship between crop nutrition and pests. Most studies assessing the response of aphids and mites to nitrogen fertiliser have documented dramatic expansion in pest numbers with increases in fertiliser rates

Weed management

- Many insects use weeds as host plants.
- Control weeds in crop but also consider adjacent fields, borders and roadsides where possible.
- Also control volunteers from previous crops

Disease management

- Diseased plants are unthrifty and susceptible to insect attack.
- Some insects can transmit diseases/viruses.
- Insect damage can expose crops to disease infestations

Hygiene and sanitation

- Some insect pests are moved by machinery (e.g. harvesters), vehicles and people – e.g. on clothing and footwear.
- Practice good farm hygiene to minimise pest movement

Pesticide use

- Minimise exposure of pesticides to bees and birds
- Apply insecticides late in the day when birds and bees have finished feeding

Environmental conditions

- Know how weather affects some pests (e.g. heavy rain may wash some aphids off plants, winds can assist insect migration, some insects reduce feeding at lower temperatures etc)

Preserve beneficial insects

- Tolerate non-economic early season damage
- Minimise early season sprays to conserve beneficials
- Learn how to encourage beneficials into your crops
- Biological formulations such as NPV, Bt and Metarhizium are highly specific and do not harm beneficials.
- Integrate cultural and biological control strategies into the production system where practical. [6]

7.2.3 Natural enemies

Beneficial species, sometimes referred to as 'natural enemies', help to control invertebrate pests as part of a successful IPM strategy. Many beneficial species occur naturally and populations can be encouraged by reducing pesticide use.

- Ladybird beetles

6 IPM Guidelines. (2016). Growing a healthy crop. http://ipmguidelinesforgrains.com.au/ipm-information/growing-a-healthy-crop/

- » Ladybird adults and larvae are predatory and consume prey. Adults and larvae range from 3 to 7 mm in length.
  - » Pests attacked: aphids, leafhoppers, thrips, mites, moth eggs and small larvae.
- Spiders
  - » Spiders consume adult insects and larvae. Groups that commonly occur in field crops include wolf, jumping and huntsman spiders.
  - » Pests attacked: most insects and mites, including other predators.
- Predatory mites
  - » Many predatory mites are found in cropping environments in Australia. Adult snout mites are 2 mm in length and are effective predators in autumn and winter. Nymphs are similar in appearance, but smaller with six legs.
  - » Pests attacked: earth mites and lucerne flea.
- Lacewings
  - » Brown and green lacewings are effective predators of a range of pests. Brown lacewing adults (6 to 10 mm) and larvae (5 mm) are both predatory. Adult green lacewings (15 mm) are not predatory; green lacewing larvae (8 mm) are camouflaged predators.
  - » Pests attacked: a wide range including moth larvae and eggs, aphids, thrips and mites.
- Carabid beetles
  - » Carabid beetle species feed mostly on ground-dwelling pests. Larvae (10 to 25 mm) and adults (5 to 25 mm) are predatory and have prominent mouthparts (mandibles) that protrude forward.
  - » Pests attacked: a wide range including true wireworms, false wireworms, moth larvae and slugs.
- Hover flies
  - » Larvae (10 mm) are effective predators of aphids. Pupae are stuck to the plant, teardrop shaped and green or brown in colour.
  - » Pests attacked: aphids.
- Damsel bugs
  - » Damsel bug adults (12 mm) and nymphs (smaller, without wings) are both predatory.
  - » Pests attacked: include moth larvae and eggs of Helicoverpa and diamondback moth, aphids, leafhoppers, mirids and mites.
- Caterpillar parasites
  - » Include beneficial species that parasitise caterpillar larvae or eggs. The adult female Trichogramma wasp (0.5 mm) lays eggs inside the moth egg. The parasitised egg turns black, but the moth larva fails to hatch; instead a parasitic wasp emerges.
  - » Pests attacked: Helicoverpa, diamondback moth, light brown apple moth, loopers and more. [7]

Conserving or supplementing beneficial insects

The impact of beneficial insects can be maximised by conserving or encouraging naturally-occurring populations and encouraging population increases, or by supplementing the natural enemy complex by releasing mass-reared beneficials into the cropping system.

Conservation and promotion of beneficial arthropods

Crop management considerations to preserve and promote beneficial activity include:

- Regular monitoring for pests and beneficials

7 S Micic, P Umina, A Weeks, H Brier. (2009). Integrated Pest Management – Factsheet. GRDC.

- Awareness of thresholds for specific pests
- Tolerance of early season damage (if the crop has time to compensate)
- Are there 'hotspots' that can be treated rather than the entire field?
- Can novel approaches be used (e.g. biological formulations such as NPV or Bt, or attractants such as Magnet®)
- Awareness of insecticide choices
- Seed treatments are generally more selective than foliar sprays foliar sprays
- Know your pesticide: selective insecticides are generally considered to be 'softer' on natural enemies, but still may be highly toxic to certain arthropod groups
- Consider longer term economic benefit (e.g. a more expensive spray now may save money over the season by reducing the risk of secondary outbreaks)

Whole-of farm considerations include:

- Farm hygiene – control weeds and volunteer crop plants to minimise pest carry-over
- Farmscaping to provide habitat for beneficials within the farming system
- Insectary crops (provide a source of nectar and enhance beneficial activity)
- Preserving native/remnant vegetation as a good habitat for beneficials (see pest-suppressive landscapes)
- Windbreaks can also offer habitat for beneficial arthropods
- Prevent pesticide drift into areas where beneficials may be residing. [8]

MORE INFORMATION

Conserving or supplementing beneficials

Insecticides and beneficial insects

When deciding whether to use chemical control in managing crop pests, ensure to consider the effects of insecticides on beneficial insects (Table 3).

Table 3: *Impact of common insecticides on beneficial insects. Note that the values provided here are generalisations and there may be exceptions (e.g. relating to specific species or time of application). Pest resurgence is included as there may be an increase in non-targeted pests following application of insecticides. This is mainly due to the demise of beneficials that may keep pests in check.*

Insecticide group	Persistence	Overall ranking	Impact on beneficial insects				
			Predatory beetles	Predatory bugs	Parasitic wasps	Spiders	Bees
FOLIAR-APPLIED							
Bio-pesticides							
Bt	Short	Low	L	L	L	L	L
Helicoverpa NPV	Short	Low	L	L	L	L	L
Metarhizium	Short	Low	L	L	L	L	L
Petroleum spray oils	Short	Low	L	L	L	L	L
Organophosphates							
omethoate	Medium	Moderate	M	M	M	L	H
dimethoate (low rate)	Short	Moderate	M	M	M	L	H
dimethoate (high rate)	Short	High	M	M	H	M	H
methidathion	Short	High	H	H	H	H	H
Indoxacarb	Medium	Low	L	L	L	L	no data
Phenyl pyrazoles (fipronil)	Medium	Low	L	L	L	M	H

8 IPM Guidelines. (2016). Conserving or supplementing beneficials. http://ipmguidelinesforgrains.com.au/ipm-information/biological-control/beneficial-insects/conservation-of-beneficials/

Insecticide group	Persistence	Overall ranking	Impact on beneficial insects				
			Predatory beetles	Predatory bugs	Parasitic wasps	Spiders	Bees
Carbamates							
pirimicarb	Short	Low	L	L	L	L	L
thiodicarb	Long	High	H	M	M	M	M
methomyl	Short	High	H	M	M	M	H
Avermectins (emamectin benzoate)	Medium	Moderate	L	H	M	M	H
Synthetic pyrethroids	Long	High	H	H	H	H	H
SEED DRESSINGS							
fipronil	Medium	Low	Limited data available. Seed dressings generally less disruptive than foliar-applied formulations.				
imidacloprid	Medium	Low					
imidacloprid + thiomethoxam	Medium	Low					

Symbols used in the table:

L – Low toxicity	nil or low impact on beneficials
M — Moderate toxicity	activity is significantly reduced but beneficial populations are able to recover in a week or so
H — High toxicity	high proportion of beneficial population killed and re-establishment will not occur for several weeks

Persistence of pest control:
Foliar applications: short = <3 days, medium = 3–7 days, long = >10 days
Seed treatments: short = 2–3 weeks, medium 3–4 weeks, long = 4–6 weeks
*Insecticides and the groups they belong to can be found in the insecticide groups table.

Information in this table has been derived from the Cotton Pest Management Guide (2014–15

7.3 Aphids

Aphids are a group of soft-bodied bugs commonly found in a wide range of crops and pastures. In field crops, plant viruses and related diseases can be transmitted by a number of insects. Aphids are considered to be the most important virus vector.

Aphids can reduce yields by direct feeding damage which causes flower and pod abortion and occasionally plant death in lupins. They transmit serious virus diseases which reduces yields and contaminate seed stocks. Some species of aphids are more difficult to control than others.

Aphids rarely cause significant feeding damage on lupin in NSW, but can transmit viruses. These insects are vectors of two potentially serious lupin viruses: Cucumber mosaic virus (CMV) and Bean yellow mosaic virus (BYMV).

Identification of crop aphids is very important when making control decisions. Distinguishing between aphids can sometimes be challenging. It can be easier in the non-winged form but is more difficult with winged aphids.

The three most common species are:

- cowpea aphid (*Aphis craccivora*)
- bluegreen aphid (*Acyrthosiphon kondoi*)
- green peach aphid (*Myzus persicae*)

Cowpea aphid

The cowpea aphid has a black body and black and white legs (Figure 2). It tends to arrive in lupin crops earlier than green peach or bluegreen aphids. They often form dense colonies on a single plant before moving on to surrounding plants and the

MORE INFORMATION

Pictorial guide to distinguish winged aphids in pulses

MORE INFORMATION

Cowpea Aphid

Bluegreen Aphid

contrast of their black bodies against green plants make them very visible. Heavy colonisation can cause rapid wilting. [9]

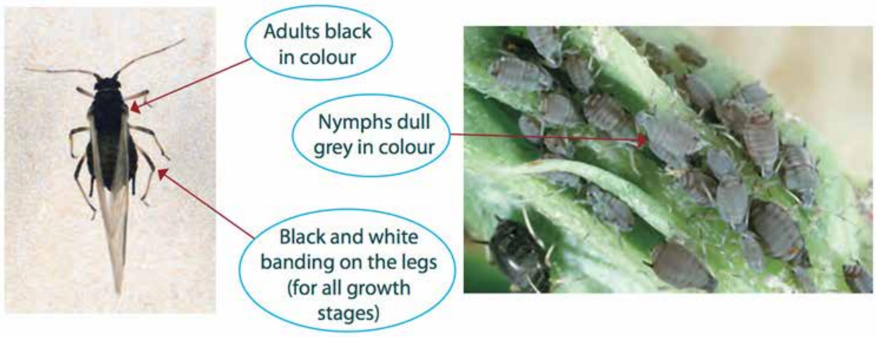


Figure 2: *Distinguishing characteristics/description of cowpea aphids*

Source: Bellati et al. 2012

Bluegreen aphid

Adults grow up to 3 mm long, are oval shaped, with long legs and antennae. They have two large cornicles that extend beyond the base of the abdomen. Both the winged and wingless forms are a matte bluish-green colour (Figure 3). Nymphs are similar to adults but are smaller in size. [10]

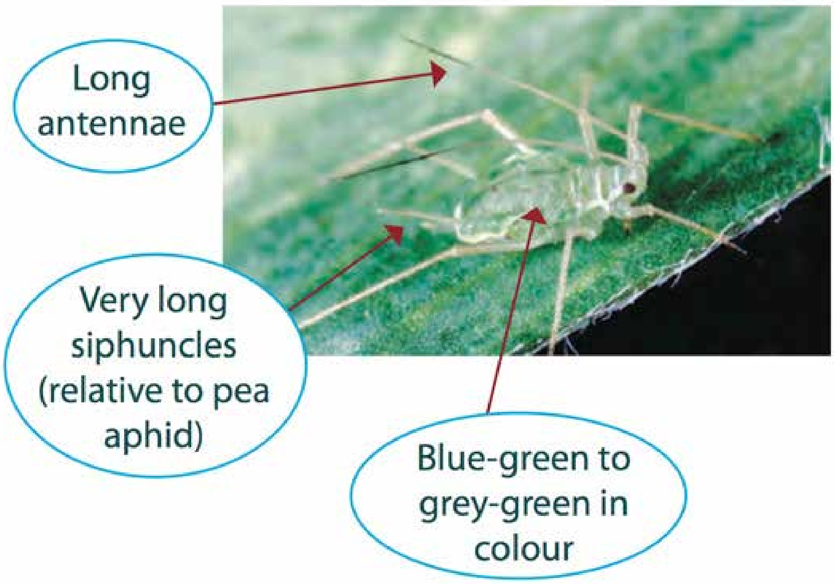


Figure 3: *Distinguishing characteristics/description of bluegreen aphid*

Source: Bellati et al. 2012

Green peach aphid

The green peach aphid (*Myzus persicae*) is a pest of many crops but primarily attacks lupins, canola and other pulse crops. They are most common in autumn and seldom cause economic losses to crops through direct feeding. However, the green peach aphid is an important vector of several plant diseases. Green peach aphids grow up to 3 mm long and vary in colour from shiny pale yellow-green, green, orange or pink. Adults are oval-shaped and can be winged or wingless. Winged adults (alates) have a

9 P Umina, S Hangartner (2015) Cowpea aphid. PestNotes, cesar Australia. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cowpea-aphid

10 P Umina, B Kimber (2015) Bluegreen aphid. PestNotes cesar Australia. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Bluegreen-aphid

dark patch on the abdomen, while wingless adults are usually quite uniform in colour (Figure 4). Nymphs are si milar to wingless adults but smaller in size. [11]

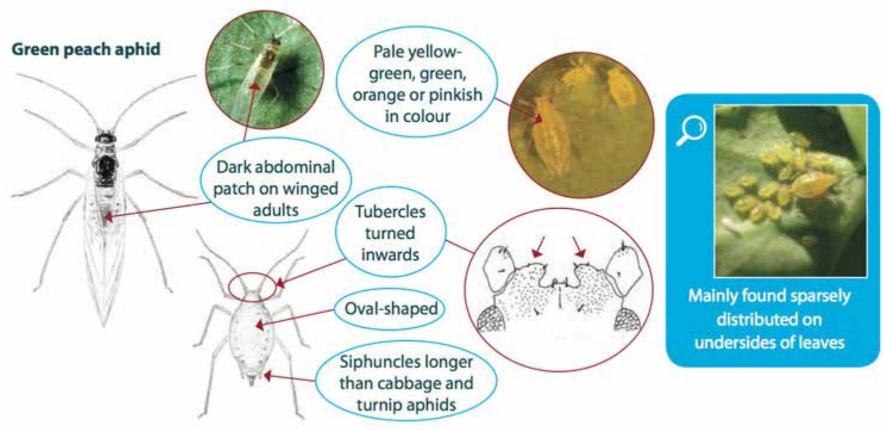


Figure 4: *Distinguishing characteristics/description of green peach aphid*

Source: Bellati et al. 2012

Resistance in green peach aphids has escalated as a result of heavy reliance on insecticides. A new testing service takes the risk out of choosing the most effective product.

Cesar is now offering a testing service to growers and advisers to determine the presence of insecticide resistance in green peach aphids populations. The tests available cover the three main insecticide groups used to control green peach aphids, and other crop aphids, in Australia: pyrethroids (Group 3A), organophosphates (Group 1B) and carbamates (Group 1A).

Cesar uses genetic assays to ensure accuracy and quick results. Resistance results are typically available 7–10 days after receiving aphid samples. Due to the nature of the genetic assays being undertaken, the cost for the resistance tests is dependent on the number of individual samples being screened at one time. Assays become more cost-effective as the number of samples increases.

MORE INFORMATION

Green peach aphid

Testing for resistance

7.3.1 Varietal resistance or tolerance

Lupin varieties differ in their susceptibility to viruses. Wonga⒟ and Jenabillup⒟ appear to have more resistance to aphid attack than other varieties. Uniform plant density, early canopy closure and retaining cereal stubble can reduce aphid visitation.

The lupin variety grown will influence the potential size of the aphid population and subsequent damage. Narrow leaf lupin varieties vary in their susceptibility to aphids (Table 4). Albus lupin are considered to be resistant to aphids.

11 P Umina (2016) Green peach aphid. PestNotes cesar Australia. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Green-peach-aphid

Table 4: *Susceptibility of narrow leaf lupin varieties to aphid colonisation and aphid borne viruses: cucumber mosaic virus (CMV; seed borne) and bean yellow mosaic virus (BYMV).*

Variety	Aphids	CMV (seed borne)	BYMV
Jenabillup⦸	R	MRMS	MR
Jindalee⦸	MRMS	MS	S
Mandelup⦸	R	MRMS	S
PBA Barlock⦸	R	MR	MS
PBA Gunyidi⦸	R	MRMS	MS
PBA Jurien⦸	R	MRMS	MR
Quilinock	MS	MR	MR
Wonga⦸	R	R	MS

Key: VS=very susceptible, S=susceptible, MS= moderately susceptible, MR=moderately resistant, R=resistant, VR=very resistant.
Source: Pulse Breeding Australia. Source: DAFWA

7.3.2 Damage caused by aphids

The extent of damage varies between seasons, but losses can be severe in years that favour aphid population development. Yield losses are greatest when aphids arrive early in the season, usually following wet seasonal conditions that provide a ‘green bridge’ of weed hosts over the summer months. Lupins are most vulnerable to aphids during budding and flowering, as severe feeding damage on growing tips can cause buds to drop, flowers to abort and reduced pod set. Some lupin varieties are more susceptible to aphids than others.

Virus transmission

Aphids are vectors of two important lupin viruses: cucumber mosaic virus (CMV) and bean yellow mosaic virus (BYMV). Yield losses are greatest when aphids have arrived early into the crop. BYMV is not seed borne, whereas CMV can be. Lupin varieties differ in their susceptibility to viruses. See links in the 'See also' section for further information on these viruses.

Feeding damage

Lupins are most vulnerable to aphids during budding and flowering, as severe feeding damage on growing tips can cause buds to drop, flowers to abort and reduced pod set. Aphids produce a sticky substance called honeydew which coats the plant surface. Sooty mould grows on this honeydew and can further reduce plant health. When monitoring look for wilted plants with aphid clusters on buds and flowers that result in flower abortion (Photos 2 and 3). [12]

12 S micic, G Thomas (2017) Management of aphids in Western Australian Lupin crops. https://www.agric.wa.gov.au/grains-research-development/management-aphids-western-australian-lupin-crops?page=0%2C0

Photo 2: *Cowpea aphid causing feeding damage to lupin.*

Source: DAFWA

Photo 3: *Bluegreen aphid on the flowering bud of a lupin plant.*

Source: DAFWA

7.3.3 Thresholds for control

Control of cowpea aphid in lupin crops in NSW is warranted at the first sign of virus infected plants or appearance of aphid clusters on flowering spikes.

Control of bluegreen aphid in lupin crops in NSW is warranted when more than 50% of plants have clusters 25 mm long on stem or 4–5 stems per m^2 with cluster 50 mm long on stems. [13]

Economic thresholds for direct feeding damage have not been established for green peach aphids. In most situations, green peach aphid insecticide treatment to prevent direct feeding damage will not be economic. Thresholds for managing aphids to prevent the incursion of aphid-vectored virus have not been established; however, virus can be transmitted by relatively few individuals, even prior to their detection within a crop. [14]

7.3.4 Management of aphids

Recommendations for Integrated Pest Management of aphids that cause direct damage to crops:

- Post-harvest, pre-sowing
  - » Remove green bridge (aphid hosts) to minimise build up during autumn and spring.
  - » Sowing into standing stubble may reduce aphid landing and delay aphid build up in crops
- Establishment and vegetative phase
- Control in-crop weeds to minimise sources of aphids.
  - » Beneficials suppress low populations and reduce the chance of outbreaks.
  - » Large bulky crops are more susceptible.
- Flowering and maturity
  - » Conserve and monitor beneficials that suppress aphids.
  - » If control is required, use soft options (e.g. pirimicarb). Use of broad spectrum pesticides may flare aphids. Check post-application for signs of flaring. [15]

Monitoring

Regularly monitor vulnerable crops during bud formation to late flowering. Aphids will generally move into paddocks from roadsides and damage will first appear on crop edges. Aphid distribution may be patchy, so monitoring should include at least 5 sampling points over the paddock. Inspect at least 20 plants at each sampling point. Visually search for aphids looking at the youngest inflorescence of each plant. Look for clusters of aphids or symptoms of leaf-curling.

Aphids are most prominent in spring, but are also active during autumn and persist through winter.

Aphid infestations can be reduced by heavy rain events or sustained frosts. If heavy rain occurs after a decision to spray has been made, but before the insecticide has been applied, check the crop again to determine if treatment is still required. [16]

Biological control

There are many effective natural enemies of aphids. Hoverfly larvae, lacewings, ladybird beetles and damsel bugs are known predators that can suppress populations. Aphid parasitic wasps lay eggs inside bodies of aphids and evidence of parasitism is seen as bronze-coloured enlarged aphid 'mummies'. As mummies develop at the latter stages of wasp development inside the aphid host, it is likely that many more aphids have been parasitized than indicated by the proportion

MORE INFORMATION

Diagnosing aphid damage in lupins

13 Hertel K, Roberts K and Bowden P. 2013. Insect and Mite control in field crops. New South Wales DPI. ISSN 1441–1773.

14 P Umina (2016) Green peach aphid. PestNotes cesar Australia. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Green-peach-aphid

15 IPM Guidelines. (2014). 'Best Bet' IPM Strategy: Winter pulse pests – Southern region. http://ipmguidelinesforgrains.com.au/wp-content/uploads/BestBet_WinterPulsesSouth2014.pdf

16 P Umina, S Hangartner. (2015). PestNotes: Cowpea aphid. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cowpea-aphid

of mummies. Naturally occurring aphid fungal diseases (*Pandora neoaphidis* and *Conidiobolyus obscurus*) can also suppress aphid populations.

Encourage aphid predators and parasites

Control by predators and parasites is very reliable when low to moderate numbers of aphids are present. However, when aphids reach high levels, predators and parasites have less impact on overall numbers of aphids. Predators commonly found in lupin crops include ladybirds, lacewings and hoverflies.

Parasites include certain wasp species which are efficient at seeking out aphids. They sting the aphid and lay an egg inside. The larvae hatches and slowly consumes the aphid. This slows or stops reproduction, and eventually kills the aphid. The parasite larvae creates a 'mummy' by spinning a cocoon inside the aphid, then pupates and soon emerges as an adult. Presence of bloated aphids with a pale gold or bronze sheen indicates parasite activity in your lupin crop (Photo 4). [17]

Photo 4: *Bloated, golden coloured aphids indicate that they have been attacked by parasitic wasps.*

Photo: L Townsend, Source: Kentucky pest news

Cultural control

Insecticides are not the preferred solution. Vectors for non-persistent (and partly semi-persistent) viruses need relatively short inoculation times – much shorter than the time needed for insecticides to kill. Insecticides can induce restlessness in insects, which may result in more inoculation attempts. Alternate management strategies include:

- Use resistant varieties
- Reduce virus sources
- Use virus free seed
- Remove infection sources e.g. weeds, volunteer crops. Control the green bridge in fallow periods.
- Interfere with vector landing on crops
- Insects are repelled by reflective surfaces e.g. straw mulches or kaolin particle film.
- Trap crops may be preferred feeding sites for vectors – preventing infection of the main crop.

17 S micic, G Thomas (2017) Management of aphids in Western Australian Lupin crops. https://www.agric.wa.gov.au/grains-research-development/management-aphids-western-australian-lupin-crops?page=0%2C0

- Mineral oils – aphids are averse to mineral oils. [18]

High sowing rates

Use a high sowing rate of at least 80 kilograms per hectare to achieve a density of 45 plants per square metre. High plant densities form a closed crop canopy faster which is less attractive to aphids.

Stubble retention

Retained stubble help to repel aphids from landing. Stubble retention may be particularly beneficial in wide-row spaced crops, which form closed canopies later than normal-row spaced crops.

Weed control

Good weed control before and after seeding decreases the availability of alternate hosts for aphids. It also reduces the spread of viruses from weeds into the lupin crop and back again. [19]

Chemical control

Seed treatment is an option for districts where aphid pressure is high in most seasons. Insecticide applied as seed dressings will help control aphid attack and the spread of viruses. Seed dressings help to protect the crop from aphids and virus transmission right from early establishment. The use of insecticide seed treatments can delay aphid colonisation and reduce early infestation and aphid feeding. Both persistently and non-persistently transmitted viruses can be controlled with seed dressings. The widespread use of neonicotinoid seed dressings does pose some risks to the build-up of natural enemies (no aphids early = nothing for them to eat) and potentially insecticide resistance.

In-crop sprays can also be applied to control aphid infestation (Table 5).

A border spray in autumn/early winter, when aphids begin to move into crops, may provide sufficient control without the need to spray the entire paddock. Avoid the use of broad-spectrum `insurance` sprays and apply insecticides only after monitoring and distinguishing between aphid species. Consider the populations of beneficial insects before making a decision to spray, particularly in spring when these natural enemies can play a very important role in suppressing aphid populations if left untouched.

Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website.

Table 5: *Registered products for controlling aphids in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Pirimicarb 500 g/kg WP	Aphidex 500 WP	0.25 kg
500 g/kg WG	Pirimicarb 500	0.25 kg
	Aphidex WG	0.25 kg
	Atlas 500 WG	0.25 kg
	Pirimicarb 500 WG	0.25 kg
	Pirimor WG	0.25 kg

Note that these treatments are registered for green peach aphids (Myzus persicae) and cowpea aphids (Aphis craccivora) only.

Source: NSW DPI

18 IPM Guidelines. (2016). Insects as virus vectors. http://ipmguidelinesforgrains.com.au/ipm-information/making-informed-control-decisions/insects-as-virus-vectors/

19 S micic, G Thomas (2017) Management of aphids in Western Australian Lupin crops. https://www.agric.wa.gov.au/grains-research-development/management-aphids-western-australian-lupin-crops?page=0%2C0

Insecticide resistance in aphids

GRDC-funded research has uncovered widespread resistance among green peach aphid populations to pirimicarb, synthetic pyrethroids and organophosphates in NSW, Qld, Vic, SA and WA. The confirmation of widespread resistance to pirimicarb is particularly concerning for pulse and oilseed growers because this chemical has been a fallback for aphid populations resistant to other chemical groups.

Pirimicarb is aphid-specific and less harmful to other invertebrates when applied to crops, so is compatible with an integrated pest management (IPM) approach. Organophosphate resistance, observed in Australia for many years, has also been identified in populations across all states. [20]

Five chemical subgroups are registered to control GPA in grain crops:

- carbamates (Group 1A);
- synthetic pyrethroids (Group 3A);
- organophosphates (Group 1B);
- neonicotinoids (Group 4A);
- and sulfoxaflor (Group 4C).

Paraffinic spray oils are also registered for suppression of GPA.

High levels of resistance to carbamates and pyrethroids are now widespread across Australia. Moderate levels of resistance to organophosphates have been observed in many populations, and there is evidence that resistance to neonicotinoids is evolving.

Recommendations for control include:

- assess aphid and beneficial populations over successive checks to determine if chemical control is warranted;
- use economic spray thresholds where available;
- where GPA is colonising crop margins in the early stages of population development, consider a border spray with an insecticide to prevent/delay the build-up of GPA and to retain beneficial insects;
- avoid repeated applications of products from the same insecticide group on GPA and other pests in the same paddock;
- do not re-spray a paddock in the same season where a known spray failure has occurred using the same product or another product from the same insecticide group, or if a spray failure has occurred where the cause has not been identified;
- to encourage beneficial insects, avoid broad-spectrum sprays, particularly early in the season;
- comply with all directions for use on product labels;
- and ensure spray rigs are properly calibrated and sprays achieve good coverage, particularly in crops with a bulky canopy. [21]

Growers are encouraged to keep an eye out for any control difficulties when applying chemicals as per label instructions, and to rotate insecticide classes to prevent resistance from developing further.

MORE INFORMATION

Resistance management strategy for green peach aphid in Australian grains

Management of aphids in Lupin crops - WA

7.4 Redlegged earth mite

Redlegged Earth Mites (RLEM) are one of the most important invertebrate pest species in Australian agriculture and are very common and widespread in pastures and most broadacre crops. They are active from autumn to late spring in southern Australia including southern NSW. Redlegged earth mites often occur in situations with other mites, such as blue oat mites, *Bryobia* mites and *Balaustium* mites.

20 S Clarry (2013) GroundCover Issue 106: Insecticide resistance increasing in aphids. GRDC. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-106-sept-oct-2013/insecticide-resistance-increasing-in-aphids

21 GRDC (2015) Resistance management strategy for the green peach aphid in Australian grains. http://ipmguidelinesforgrains.com.au/wp-content/uploads/RMS-for-GPA_revised-2015.pdf

RLEM is approximately 1 mm in length with a velvety black body and eight orange-red coloured legs. Newly hatched mites are pinkish-orange with six legs and are 0.2 mm long (Figure 5).

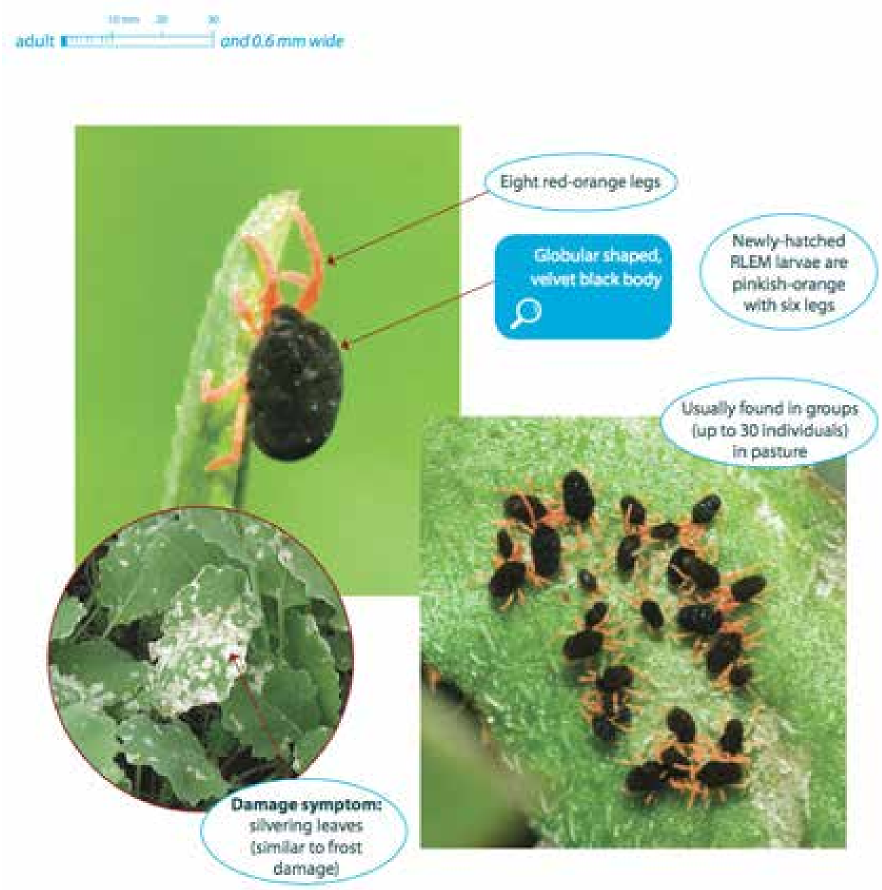


Figure 5: *Distinguishing characteristics/description of redlegged earth mites*

Source: Bellati et al. 2012

Redlegged earth mites are often found on the leaf surface in feeding aggregations, of up to 30 individuals. In the warmer part of the day, redlegged earth mites tend to gather at the base of plants, sheltering in leaf sheaths and under debris.

It is important to correctly identify redlegged earth mites because other mite species respond differently to registered pesticides. Redlegged earth mites are commonly controlled using insecticides, however, non-chemical options are becoming increasingly important due to evidence of resistance and concerns about long-term sustainability. [22]

7.4.1 Varietal resistance or tolerance

All crops and pastures, with lupins, canola, cereals and legume seedlings the most susceptible to attack. Weeds can also act as alternative hosts, particularly capeweed.

7.4.2 Damage caused by RLEM

Mite-damaged leaves have a rasped silvery appearance, turn brown and shrivel. Damage is most severe when cold, wet or dry conditions slow seedling growth. [23]

22 P Umina, G MacDonald. (2015). PestNotes: Redlegged Earth Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

23 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

Feeding causes silvering or white discoloration of leaves and distortion or shriveling in severe infestations (Photo 5). Affected seedlings can die at emergence with high mite populations. Feeding symptoms can be mistaken for frost damage. Redlegged earth mites have been found to be directly responsible for a reduction in pasture palatability.

Photo 5: *Redlegged earth mites (RLEM) cause the edges of leaves to turn brown and shrivel.*

Source: Pulse Australia

7.4.3 Thresholds for control

Control of RLEM in lupin is warranted when 50 mites per 100cm^3 can be detected. [24]

7.4.4 Management of RLEM

Monitoring

Mites are best detected feeding on the leaves in the morning or on overcast days. If mites are not observed on plant material, inspect soil for mites. An effective way to sample mites is to use a standard petrol-powered garden blower/vacuum machine. A fine sieve or stocking is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface. [25]

Biological control

French *Anystis* mites can suppress populations in some pastures. Snout mites and other predatory mites are also effective natural enemies. Leaving shelterbelts or refuges between paddocks will help maintain natural enemy populations. [26]

Cultural control

Clean cultivation in autumn and attention to weeds on fence lines is also essential. If possible, keep a distance from paddocks of the species that host mites, such as other pulses, pasture legumes (including sub clover and lucerne) and oilseeds, and control weeds such as thistles and capeweed along paddock borders and non-crop areas. [27]

Do not sow susceptible crops (e.g. canola) into pastures or paddocks known to contain high mite numbers. Rotate paddocks with non-preferred crops (e.g. chickpeas). Pre- and post- sowing weed management (particularly broadleaf weeds) is important. Heavy pasture grazing in spring can help to reduce mite numbers the following autumn. [28]

24 P Umina, G MacDonald. (2015). PestNotes: Redlegged Earth Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

25 P Umina, G MacDonald. (2015). PestNotes: Redlegged Earth Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

26 P Umina, G MacDonald. (2015). PestNotes: Redlegged Earth Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

27 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

28 P Umina, G MacDonald. (2015). PestNotes: Redlegged Earth Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

Chemical control

For low-moderate mite populations, insecticide seed dressings are an effective method. Seed treatments allow lower quantities of insecticide than spraying. Current recommendations are Imidacloprid (4A) or Poncho® Plus (2x4A) or fipronil (2B) or Cruiser® Opti (4A+3A) if SPs (3A) will not be used at post-emergence (Window 3).

Rotate chemical classes of insecticides (Table 6). Avoid prophylactic sprays; apply insecticides if control is warranted. Pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, before adults commence laying eggs. Insecticides do not kill mite eggs. Border spraying can be an effective way to control mites, as mites will often move in from crop edges and roadside vegetation. Carefully timed spring spraying using TIMERITE® will reduce mite populations the following autumn, but could also exacerbate other mite problems. [29]

Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website.

Table 6: *Registered products for controlling Redlegged Earth Mites in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Alpha-cypermethrin* 100 g/L EC 250 g/L SC	Alpha-Scud Elite	50 mL[2]
	Astound Duo	50 mL[2]
	Dictate 100	50 mL[2]
	Dominex Duo	50 mL[2]
	Fastac Duo	50 mL[2]
	Alpha Forte 250 SC	40 mL
Beta-cyfluthrin 25 g/L EC	Bulldock Duo	0.2
Bifenthrin 100 g/L EC	Arrow 100 EC[3]	50–100 mL
	Bifenthrin 100 EC[3]	50–100 mL
	Ospray Bifenthrin 100 EC[3]	50–100 mL
	Talstar 100 EC[3]	50–100 mL
Chlorpyrifos* 500 g/L EC	Conquest Chlorpyrifos 500	0.14–0.3
	Cyren 500 EC	0.14–0.3
	Lorsban 500 EC	0.14–0.3
	Strike-Out 500 EC	0.14–0.3
Esfenvalerate 50 g/L EC	Sumi-Alpha Flex	50–70 mL[5]
Gamma-cyhalothrin 150 g/L CS	Trojan	8 mL[9]
Lambda-cyhalothrin 250 g/L CS	Flipper 250 CS	9 mL[8]
	Karate (Zeon Tech)	9 mL[8]
	Kung Fu 250	9 mL[8]
	Matador (Zeon Tech)	9 mL[8]
Maldison 1169 g/L ULV	Fyfanon ULV	0.225

29 P Umina, G MacDonald. (2015). PestNotes: Redlegged Earth Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

Chemical formulation	Registered trade names	Application (litres per ha)
Omethoate* 290 g/L SL	All-Mitey 290 SL **	0.1***
	Le-mat 290 SL **	0.1***
	Mite Master 290 **	0.1***
	Omen 290 **	0.1***
	Omethoate 290 SL**	0.1***

*Numerous other generic products are also registered.
1 Registered for native budworms (*Helicoverpa punctigera*) only.
4 Registered for corn earworms (*Helicoverpa armigera*) at 0.5 L/ha.
5 Also registered at 100 mL/ha for bare earth, pre-emergent application.
6 Registered in southern NSW only.
7 Registered for native budworms (*Helicoverpa punctigera*) only
8 Registered rate may be less effective against blue oat mites (Penthaleus major
**Also registered for bryobia mites at 0.12 L/ha
***Also registered as a barrier spray for redlegged earth mites (Halotydeus destructor) at 0.3 L/ha

Source: NSW DPI

Insecticide resistance in RLEM

As of 2017, scientists have for the first time discovered insecticide resistance in redlegged earth mite in the Southern cropping region. Studies on several RLEM populations in South Australia have been confirmed resistant to both synthetic pyrethroids, including bifenthrin and alpha-cypermethrin, and organophosphates, including omethoate and chlorpyrifos.

This is the first time resistance has been detected in Australian RLEM populations outside of Western Australia, where resistance can be found throughout the WA grain belt. Resistant RLEM is a threat to the profitability of a range of Australian crops and pastures, with lupins, canola and legume seedlings the most susceptible to attack.

To guide growers and their advisers in their efforts to control RLEM and reduce the risk of resistance occurring, a Resistance Management Strategy (RMS) for South Australia, Tasmania, Victoria and southern New Wales has been developed.

The strategy's key recommendations include not using the same chemical groups across successive spray windows (on multiple generations of mites) and reserving co-formulations (or chemical mixtures) for situations where damaging levels of pests are present and a single active ingredient is unlikely to provide adequate control.

Other recommendations in the RMS, as part of an overall integrated pest management (IPM) approach include:

- Consider the impact on target and non-target pests and beneficial invertebrates when applying insecticide sprays. Where possible, use target-specific 'soft' insecticides, especially in paddocks with resistant RLEM;
- Bee-aware;
- Correctly identify the mite species to ensure the most effective insecticide and recommended label rate is used. Misidentification and incorrect insecticide selection may result in poor control and contribute to selection for resistance;
- Assess mite and beneficial populations over successive checks to determine if chemical control is warranted. Use economic spray thresholds where available and do not spray if pest pressure is low;
- Monitor RLEM numbers before and after insecticide application to determine control levels achieved. Where poor control is observed re-evaluate future control tactics and seek expert advice.

Growers are encouraged to use a RLEM insecticide resistance testing service, available at no extra cost to growers through a national GRDC-funded project led by the University of Melbourne, in collaboration with cesar, the Department of Agriculture and Food Western Australia and CSIRO. [30]

MORE INFORMATION

Redlegged Earth Mite RMS

Redlegged Earth Mite insecticide resistance discovery

30 S Watt (2017) Redlegged earth mite insecticide resistance discovery. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/08/redlegged-earth-mite-rms

7.5 Blue oat mite

Blue oat mites are important crop and pasture pests in southern Australia. They are commonly found in Mediterranean climates of New South Wales, Victoria, South Australia, Western Australia and eastern Tasmania. They are also found in parts of southern Queensland. There are three morphologically similar species of blue oat mites that differ in their distributions, pesticide tolerances and host plant preferences.

A microscope is required to distinguish the morphological differences between *Penthaleus major*, *Penthaleus falcatus* and *Penthaleus tectus*. *P. major* has long setae arranged in four to five longitudinal rows, while *P. falcatus* has a higher number of short setae scattered irregularly. *P. tectus* has setae of medium length and number.

Adult blue oat mite are approximately 1 mm in length and have a blue-black body with a distinctive red mark on their back which differentiates them from Redlegged earth mites. They have eight red-orange legs. The nymphs are pinkish-orange in colour with six legs on hatching, but soon change colour to brownish and then green, before reaching the adult stage (Figure 6).

Figure 6: *Distinguishing characteristics/description of blue oat mites*

Source: Bellati et al. 2012

Blue oat mites are active in the cool wet part of the year, usually between April and late October. During this time they pass through two or three generations, with each generation lasting eight to ten weeks. They spend the remaining months protected as diapause or over-summering eggs that are resistant to the heat and desiccation of summer. These eggs hatch in autumn following cool temperatures and adequate rainfall, when conditions are optimal for mite survival. The climatic conditions are similar, but probably different to those that trigger egg hatch of redlegged earth mites. Swarms of young mites will then attack emerging crop and pasture seedlings.

Female mites deposit eggs either singly or in clusters of three to six on the leaves, stems and roots of food plants or on the soil surface.

Blue oat mites reproduce asexually. This mode of reproduction results in populations made up of female 'clones' that can respond differently to environmental and chemical conditions than mites reproducing sexually. This may influence the likelihood of populations developing resistance and means blue oat mite populations could respond differently to control strategies.

Blue oat mites often coexist with redlegged earth mites and both are typically active from autumn to late spring. Blue oat mites spend the majority of their time on the soil surface, rather than on the foliage of plants. They are most active during the cooler parts of the day, tending to feed in the mornings and in cloudy weather (particularly in spring). They seek protection during the warmer part of the day on moist soil surfaces or under leaf litter, and may even dig into the soil under extreme conditions. [31]

7.5.1 Varietal resistance or tolerance

Lupin can be vulnerable to mite damage, especially at the seedling stage.

7.5.2 Damage caused by BOM

Mite-damaged leaves have a rasped silvery appearance, turn brown and shrivel (Photo 6). Damage is most severe when cold, wet or dry conditions slow seedling growth. [32]

Affected seedlings can die at emergence with high mite populations. Unlike redlegged earth mites, blue oat mites typically feed singularly or in very small groups. [33]

Photo 6: *Blue oat mite damage to crop leaf.*

Source: GRDC

7.5.3 Thresholds for control

There are no economic thresholds established for control of this pest.

7.5.4 Management of BOM

Key IPM strategies:

31 P Umina, S Hangartner. (2015). PestNotes: Blue Oat Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Blue-oat-mite

32 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

33 P Umina, S Hangartner. (2015). PestNotes: Blue Oat Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Blue-oat-mite

- Pre-season
  - » High risk when:
  - » history of high mite pressure
  - » susceptible crop (canola, pasture, lucerne)
  - » rotating from pasture to crop
  - » seasonal forecast for dry or cool, wet conditions.
  - » If High risk, consider:
  - » planting a less susceptible crop
  - » controlling mites in the pasture to reduce carryover
  - » using a seed dressing on susceptible crops
- Pre-sowing
  - » monitor frequently until crop establishment
  - » consider a higher sowing rate to compensate for seedling loss
  - » consider scheduling a post plant pre- emergence treatment. Note: bare-earth treatments will impact on predators of slugs.
- Emergence
- Monitor to establishment
  - » be aware of edge effects (mites moving from weed hosts)
  - » consider an insecticide application prior to winter eggs production to suppress populations and reduce risk in following season.
  - » Crop establishment
  - » As the crop grows, it becomes less susceptible to mites unless growth is slowed by dry or cool, wet conditions. [34]

Monitoring

Inspect susceptible pastures and crops from autumn to spring for the presence of mites and evidence of damage. It is important to inspect crops regularly in the first three to five weeks after sowing. Mites are best detected feeding on the leaves in the morning or on overcast days. If mites are not observed on plant material, inspect the soil for mites. An effective way to sample mites is to use a standard petrol powered garden blower/vacuum machine. A fine sieve or stocking is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface. [35]

Biological control

French *Anystis* mites can suppress populations in some pastures. Snout mites and other predatory mites are also effective natural enemies. Leaving shelterbelts or refuges between paddocks will help maintain natural enemy populations.

Cultural control

Clean cultivation in autumn and attention to weeds on fence lines is also essential. If possible, keep a distance from paddocks of the species that host mites, such as other pulses, pasture legumes (including sub clover and lucerne) and oilseeds, and control weeds such as thistles and capeweed along paddock borders and non-crop areas.

Rotate paddocks with non-preferred crops (*P. major* – canola; *P. tectus* – chickpeas; *P. falcatus* – wheat, barley). Pre- and post- sowing weed management (particularly broad-leafed weeds) is important.

34 IPM Guidelines. (2014). 'Best Bets' IPM Strategies for establishment pests in the Northern region. http://ipmguidelinesforgrains.com.au/wp-content/uploads/BestBet_EstablishmentNorth2014.pdf

35 P Umina, S Hangartner. (2015). PestNotes: Blue Oat Mite. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Blue-oat-mite

Chemical control

Chemicals are the most common method of control against earth mites. Unfortunately, all currently registered pesticides are only effective against the active stages of mites; they do not kill mite eggs. While a number of chemicals are registered in pastures and crops (Table 7), differences in tolerance levels between species complicates management of blue oat mites. P. falcatus has a higher tolerance to a range of pesticides and this is often responsible for chemical control failures. Ensure pesticide sprays are applied at the full registered rate. P. major and P. tectus have lower tolerances to pesticides and are more easily controlled.

For low-moderate mite populations, insecticide seed dressings are an effective method. Avoid prophylactic sprays; apply insecticides only if control is warranted and if you are sure of the mite identity. Pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, before adults commence laying eggs. Spring spraying using TIMERITE® is largely ineffective against blue oat mites and is not recommended.

Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website for up-to-date registrations.

Table 7: *Registered products for controlling Blue Oat Mites in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Alpha-cypermethrin* 100 g/L EC 250 g/L SC	Alpha-Scud Elite	50 mL
	Astound Duo	50 mL
	Dictate 100	50 mL
	Dominex Duo	50 mL
	Fastac Duo	50 mL
	Alpha Forte 250 SC	20 mL
Aeta-cyfluthrin 25 g/L EC	Bulldock Duo	0.2
Bifenthrin 100 g/L EC	Arrow 100 EC[3]	0.1
	Bifenthrin 100 EC[3]	0.1
	Ospray Bifenthrin 100 EC[3]	0.1
	Talstar 100 EC[3]	0.1
Chlorpyrifos* 500 g/L EC	Conquest Chlorpyrifos 500	0.14–0.3
	Cyren 500 EC	0.14–0.3
	Lorsban 500 EC	0.14–0.3
	Strike-Out 500 EC	0.14–0.3
Esfenvalerate 50 g/L EC	Sumi-Alpha Flex	50–70 mL[5]
Omethoate* 290 g/L SL	All-Mitey 290 SL **	0.1
	Le-mat 290 SL **	0.1
	Mite Master 290 **	0.1
	Omen 290 **	0.1
	Omethoate 290 SL**	0.1

3 Registered for bryobia mites at 0.2 L/ha. Apply to bare soil.
5 Also registered at 100 mL/ha for bare earth, pre-emergent application.
*Numerous other generic products are also registered.
** Also registered for bryobia mites at 0.12 L/ha

Source: NSW DPI

Insecticide resistance in BOM

Cesar researchers have found high levels of tolerance to several organophosphates and/or synthetic pyrethroids in blue oat mites. These findings show that current pesticide usage is unlikely to be a sustainable practice and may help to explain the increasing number of reports that these species are persisting in the field even after multiple chemical applications.

Correct identification of mite species is the first step in effective control and minimisation of resistance. It is important to correctly identify the pest present because these mite species respond differently to registered pesticides, and therefore insecticide products and rates need to be chosen accordingly. The wrong chemical treatment will cost money and only act to increase the selection pressure for further resistance development.

Clean fallowing and controlling weeds around crop and pasture perimeters will act to reduce mite numbers.

Avoid insurance sprays as much as possible. Only use pesticides after careful monitoring and correct identification of pest species. If BOMs are at damaging levels carefully timed spring spraying can be an effective control method. Ensure pesticide sprays are applied at the full registered rates.

Growers should monitor crops for possible resistance and collect samples for testing if resistance is expected.

A resistance testing service is available through a GRDC-funded project led by the University of Melbourne, in collaboration with cesar, the Department of Agriculture and Food, Western Australia (DAFWA), CSIRO and the University of WA.

MORE INFORMATION

Test your mites for resistance

Table 8: *Registered products for controlling Redlegged Earth Mites in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Alpha-cypermethrin* 100 g/L EC 250 g/L SC	Alpha-Scud Elite	50 mL[2]
	Astound Duo	50 mL[2]
	Dictate 100	50 mL[2]
	Dominex Duo	50 mL[2]
	Fastac Duo	50 mL[2]
	Alpha Forte 250 SC	40 mL
Beta-cyfluthrin 25 g/L EC	Bulldock Duo	0.2
Bifenthrin 100 g/L EC	Arrow 100 EC[3]	50–100 mL
	Bifenthrin 100 EC[3]	50–100 mL
	Ospray Bifenthrin 100 EC[3]	50–100 mL
	Talstar 100 EC[3]	50–100 mL
Chlorpyrifos* 500 g/L EC	Conquest Chlorpyrifos 500	0.14–0.3
	Cyren 500 EC	0.14–0.3
	Lorsban 500 EC	0.14–0.3
	Strike-Out 500 EC	0.14–0.3
Esfenvalerate 50 g/L EC	Sumi-Alpha Flex	50–70 mL[5]
Gamma-cyhalothrin 150 g/L CS	Trojan	8 mL[9]

Chemical formulation	Registered trade names	Application (litres per ha)
Lambda-cyhalothrin 250 g/L CS	Flipper 250 CS	9 mL[8]
	Karate (Zeon Tech)	9 mL[8]
	Kung Fu 250	9 mL[8]
	Matador (Zeon Tech)	9 mL[8]
Maldison 1169 g/L ULV	Fyfanon ULV	0.225
Omethoate* 290 g/L SL	All-Mitey 290 SL **	0.1***
	Le-mat 290 SL **	0.1***
	Mite Master 290 **	0.1***
	Omen 290 **	0.1***
	Omethoate 290 SL**	0.1***

*Numerous other generic products are also registered.
1 Registered for native budworms (*Helicoverpa punctigera*) only.
4 Registered for corn earworms (*Helicoverpa armigera*) at 0.5 L/ha.
5 Also registered at 100 mL/ha for bare earth, pre-emergent application.
6 Registered in southern NSW only.
7 Registered for native budworms (*Helicoverpa punctigera*) only
8 Registered rate may be less effective against blue oat mites (Penthaleus major).
**Also registered for bryobia mites at 0.12 L/ha
***Also registered as a barrier spray for redlegged earth mites (Halotydeus destructor) at 0.3 L/ha
Source: NSW DPI

7.6 Balaustium mite

Balaustium mites are emerging as a significant crop pest in agricultural areas across southern Australia. They are the largest of the pest mites commonly found in broadacre crops. This species has a high natural tolerance to many insecticides and will generally survive applications aimed at other mite pests. Other strategies that are not reliant on chemicals, such as early control of summer weeds, should be considered.

Balaustium mites are broadly distributed across the southern coastal regions of Australia. They are sporadically found in areas with a Mediterranean climate in New South Wales, Victoria, South Australia and Western Australia. *Balaustium* mites are typically active from March to November, although mites can persist on green feed during summer if available.

All mites are wingless and have four pairs of legs, no external segmentation of the abdomen and individuals appear as a single body mass.

Balaustium mites grow to 2 mm in length and have a rounded red-brown body with eight red-orange legs (Figure 7). They are easily distinguished from other crop mites as they are much larger in size. Adults are covered with short stout hairs and are slow moving. They have distinctive pad like structures on their forelegs. Newly hatched mites are bright orange with six legs and are only 0.2 mm in length.

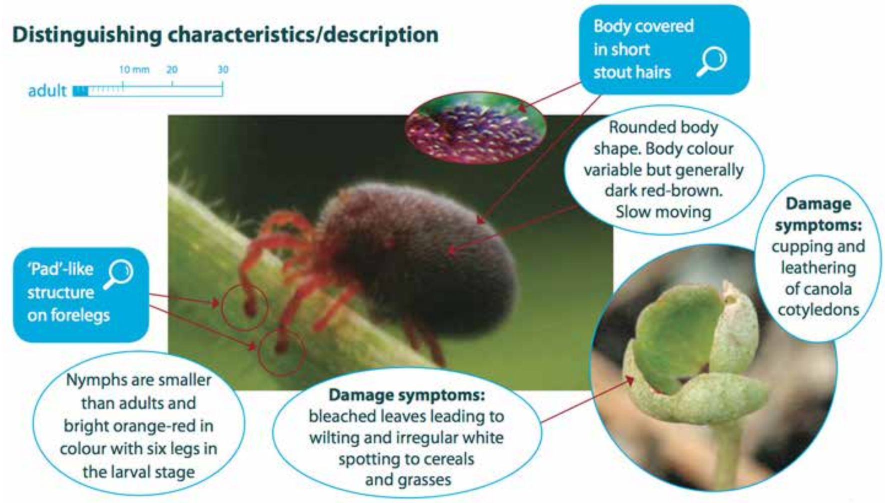


Figure 7: *Distinguishing characteristics/description of Balaustium mites*

Source: Bellati et al. 2012

7.6.1 Varietal resistance or tolerance

All crops and pasture can be attacked, but lupins, canola and cereals are the most susceptible crops, particularly at the seedling stage. Some broadleaf weeds such as capeweed are alternative host plants.

7.6.2 Damage caused by Balaustium mite

Balaustium mites feed on plants using their adapted mouthparts to probe the leaf tissue of plants and suck up sap. In most situations they cause little damage, however, when numbers are high and plants are already stressed due to other environmental conditions, significant damage to crops can occur. Under high infestations, seedlings or plants can wilt and die. Balaustium mites typically attack leaf edges and leaf tips of plants (Photo 7). In pulses, Balaustium mites cause irregular white spotting or bleaching of the leaves. Under good growing conditions crops are often able to outgrow the damage. Recorded damage by these mites has markedly increased in the past decade.

Photo 7: *Balaustium mite feeding damage on lupin.*

Source: cesar

7.6.3 Thresholds for control

There are no economic thresholds established for this pest.

7.6.4 Management of Balaustium mite

Monitoring

Inspect susceptible pastures and crops from autumn to spring for the presence of mites and evidence of damage. It is important to inspect crops regularly in the first three to five weeks after emergence because seedlings are most susceptible to feeding damage. Crops sown into paddocks that were pasture the previous year should be regularly inspected. *Balaustium* mites can be difficult to find during dewy or wet conditions and are best detected during the warmer parts of the day. An effective way to sample mites is to use a standard petrol powered garden blower/vacuum machine. A fine sieve or stocking is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface.

Biological control

There are no known biological control agents for Balaustium mites.

Cultural control

Early control of summer weeds (especially capeweed and grasses), within and around paddocks, can help prevent mite outbreaks. Avoid volunteer grasses and broadleaf weeds within susceptible crops. Rotating crops or pastures with non-host crops can also reduce pest colonisation, reproduction and survival (e.g. prior to planting a susceptible crop like canola or a cereal, sow a broadleaf such as vetch).

Chemical control

Management strategies that are not reliant on chemicals should be considered for the control of *Balaustium* mites. This species has a high natural tolerance to many insecticides and will generally survive applications aimed at other mite pests. Pyrinex® Super is the only insecticide registered to control Balaustium mites in Australian broadacre, and is currently only registered against this species in canola crops. [36]

7.7 Bryobia mite

There are over 100 species of *Bryobia* mite worldwide, with at least seven found in Australian cropping environments. Unlike other broadacre mite species, which are typically active from autumn to spring, *Bryobia* mites prefer the warmer months of the year. *Bryobia* mites are smaller than other commonly occurring pest mites. They attack pastures and numerous winter crops earlier in the season.

Bryobia mites (sometimes referred to as clover mites) are sporadic pests typically found in warmer months of the year, from spring through to autumn. They are unlikely to be a problem over winter, however, they can persist throughout all months of the year. They are broadly distributed throughout most agricultural regions in southern Australia with a Mediterranean-type climate, including New South Wales, Western Australia, Victoria and South Australia. They have also been recorded in Queensland and Tasmania.

The seven species of *Bryobia* mites found in Australia look very similar. *Bryobia* mites are smaller than other commonly occurring pest mites, although they reach no more than about 0.75 mm in length as adults. They have an oval shaped, dorsally flattened body that is dark grey, pale orange or olive in colour and have eight pale red/orange legs. The front pair of legs is much larger; approximately 1.5 times their body length. If seen under a microscope, they have a sparsely distributed set of broad, spade-like hairs, appearing like white flecks (Figure 8).

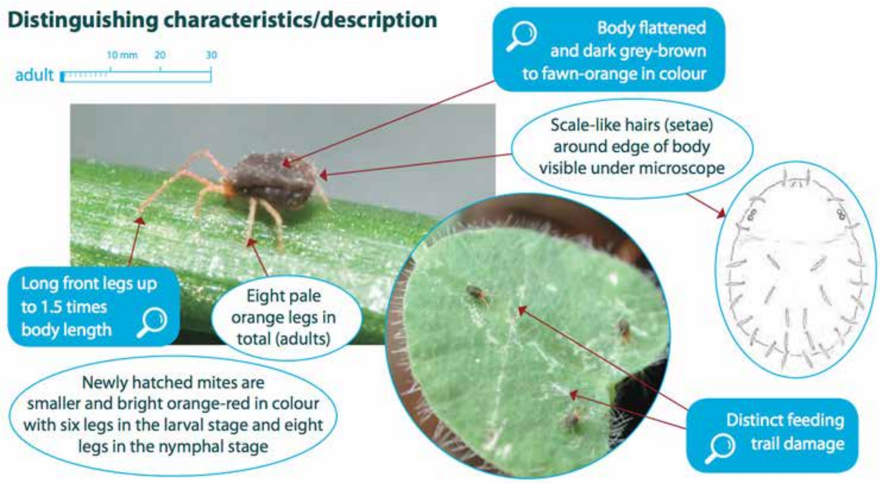


Figure 8: *Distinguishing characteristics/description of Bryobia mites*

Source: Bellati et al. 2012

36 P Umina, S Hangartner (2015) Balaustium mites. cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Balaustium-mite

7.7.1 Varietal resistance or tolerance

Bryobia mites have a preference for the broadleaf plants, such as lupins, canola, vetch, lucerne and clover, but will also attack cereals.

7.7.2 Damage caused by Bryobia mite

Bryobia mites tend to cause most damage in autumn where they attack newly establishing pastures and emerging crops, greatly reducing seedling survival and retarding development. They feed on the upper surfaces of leaves and cotyledons by piercing and sucking leaf material. This feeding causes distinctive trails of whitish-grey spots on leaves (Photo 8). Extensive feeding damage can lead to cotyledons shriveling. On grasses, *Bryobia* mite feeding can resemble that of redlegged earth mites.

Photo 8: *Long trails of whitish grey spots on top of canola cotyledons caused by Bryobia mite feeding*

Source: cesar

7.7.3 Thresholds for control

There are no economic thresholds established for this pest.

7.7.4 Management of Bryobia mite

Monitoring

Inspect paddocks during early autumn and spring when *Bryobia* mites are more problematic. *Bryobia* mites are difficult to detect during early mornings or in wet conditions and are most active during the warmer parts of the day. Look for mites and evidence of feeding damage on newly established crops, as well as clovers and brassica weeds prior to sowing. Unlike many other species of mites, which spend a lot of time on the soil surface, *Bryobia* mites are mostly found on the lower and upper leaf surfaces of plants. An effective way to sample mites is to use a standard petrol powered garden blower/vacuum machine. A fine sieve or stocking is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface.

Biological

There are currently no known biological control agents for *Bryobia* mites in Australia.

Cultural

Crops that follow pastures with a high clover content are most at risk. Avoid planting susceptible crops such as canola, lupins, vetch and lucerne into these paddocks. Early control of summer and autumn weeds within and around paddocks, especially broadleaf weeds such as capeweed and clovers, can help prevent mite outbreaks.

Chemical

Some insecticides are registered for *Bryobia* mites (Table 9), however, be aware that recommended rates used against other mites might be ineffective against *Bryobia* mites. *Bryobia* mites have a natural tolerance to several chemicals. Insecticides do not kill mite eggs. Generally organophosphate insecticides provide better control against *Bryobia* mites than synthetic pyrethroids. [37]

Table 9: *Registered products for controlling Bryobia in lupins in the Northern region. Apply to bare soil.*

Chemical formulation	Registered trade names	Application (litres per ha)
Bifenthrin 100 g/L EC	Arrow 100 EC	0.2
	Bifenthrin 100 EC	0.2
	Ospray Bifenthrin 100 EC	0.2
	Talstar 100 EC	0.2
Omethoate* 290 g/L SL	All-Mitey 290 SL	0.12
	Le-mat 290 SL	0.12
	Mite Master 290	0.12
	Omen 290	0.12
	Omethoate 290 SL	0.12

Source: NSW DPI

7.8 Thrips

Onion thrips (*Thrips tabaci*) and plague thrips (*Thrips imagines*) are 2 mm long, cigar shaped and range in colour from yellow-orange to dark grey (Photo 9). They have tiny, narrow wings carried over the back. Nymphs are similar in shape, pale yellow to orange-yellow, wingless and smaller. Adults and nymphs pierce plant tissue and suck sap.

37 P Umina, G McDonald (2015) Bryobia mite. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Bryobia-mite

Photo 9: *Thrips viewed close up.*

Source: DAFWA

7.8.1 Varietal resistance or tolerance

Lupin can be susceptible to thrips.

7.8.2 Damage caused by thrips

Thrips can start to damage a young plant while it is still below the soil surface and continue for a few weeks after emergence. The damage is caused by feeding or ovipositioning (egg laying) in the soft plant tissue. Thrips can cause reduced vigour, and flower and early pod abortion. Thrips can be particularly damaging to albus lupin. Adults and nymphs pierce plant tissue and suck sap, producing distorted leaves (Photo 10). Flower abortion occurs in extreme cases.

Photo 10: *Distorted lupin leaves cause by thrip damage.*

Source: DAFWA

7.8.3 Thresholds for control

Critical control decisions should be made at early flowering. Control threshold is 1–2 thrips per open flower, not 1–2 per flowering spike.

7.8.4 Management of thrips

Affected plants often compensate for damage and yield is not affected, therefore there is no benefit in spraying for thrip control at plant emergence. However, it is important to monitor for thrips from early flowering, using a hand lens to check growing points.

There are some products registered from controlling thrips in the Northern region (Table 10). Before implementing any chemical control, consider that thrips are also important predators of spider mites, other thrips and small eggs. Apply a narrow band spray over the seedlings to reduce the impact on predators such as spiders in the inter-row. In crops where there is an edge effect (more damage closest to the cereals), consider only spraying the severely damaged proportion of the crop. Spraying after damage symptoms are manifested is usually too late to reduce damage symptoms, unless thrips keep invading from surrounding cereals over an extended period of time.

Where possible, leave some unsprayed strips to see whether pesticide application was really needed and how crops recover from thrips damage. It would also be useful to photograph tagged plants over time in sprayed and unsprayed parts of the crop to ascertain whether there is a variation in time of flowering and maturity, and yield. [38]

Table 10: *Registered products for controlling thrips in lupins in the Northern region. Note that this product is registered in southern NSW only.*

Chemical formulation	Registered trade names	Application (litres per ha)
Esfenvalerate 50 g/L EC	Sumi-Alpha Flex	0.13

Source: NSW DPI

Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website for up-to-date chemical registrations.

7.9 Mirids

Influxes of mirid adults often coincide with northwest winds in spring. There is also evidence of long distance migration, possibly from inland areas, associated with weather fronts. This may be the cause of some of the widespread and repeated influxes of mirids sometimes observed in grain and cotton growing regions early in the summer.

Green mirid adults are 7 mm long, pale green, often with red markings and have clear wings folded flat on the back (Photo 11). Adults and nymphs are very mobile with antennae nearly as long as the body. Green mirid nymphs have a pear-shaped body and the tips of the antennae are reddish brown.

Brown mirids are similar in shape, but the adults may be slighly larger (8 mm), and the front part of the body is brown instead of green when viewed from the top (i.e. the head and thorax). The nymphs have banded antennae, alternating red-brown and white.

Crop mirid adults are 7 mm long, grey-green on top and bright green underneath. Nymphs are green with brown and white striped antennae and a black spot on the back. [39]

38 DAFWA (2017) Diagnosing thrips in lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-thrips-lupins K Charleston, H Brier (2014) Seedling thrips in spring mungbean crops. The Beatsheet. http://thebeatsheet.com.au/seedling-thrips-in-spring-mungbean-crops/

39 DAF Qld (2010) Mirids, green, brown and crop. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/mirids

Photo 11: *Mirid*

7.9.1 Damage caused by mirids

Mirids are sucking insects and feed by piercing the plant tissue and releasing a chemical that destroys cells in the feeding zone. This causes plant tissue to discolour and die. Mirids prefer to feed on flowers, buds and young pods, causing these to abort (shed). Mirids may also attack more mature pods, damaging the seeds inside without causing shedding.

Medium and large mirid nymphs (instars 3–5) are as damaging as adults. Although small mirid nymphs (instars 1–2) are less damaging, they soon develop into larger more damaging pests (within 3–5 days).

7.9.2 Management of thrips

Biological control

Damsel bugs, big-eyed bugs, predatory shield bugs, as well as lynx, night stalker and jumping spiders are known to feed on mirid adults, nymphs and eggs. Naturally occurring fungi (e.g. *Beauvaria*) may also infect and kill mirids, but are rarely observed in the field.

Cultural control

A crop that has a short flowering period reduces the risk of mirid damage. Flowering periods can be shortened by planting on a full moisture profile and by watering crops just before budding. Consider planting crops in at least 50 cm rows (as opposed to broadcast planting) to facilitate easier pest sampling.

MORE INFORMATION

IPM Guidelines - Mirids

Control weeds (mirids move into crops as alternative hosts dry off). Hosts include wild turnips, wild beans, wild sunflower, marshmallow, noogoora burr, verbena and thistles.

Mirids can migrate between crops. Cultivated mirid hosts include cotton, safflower, sunflower, and lucerne.

Strip cropping with lucerne may prevent movement of mirids into pulse crops as mirids have a preference for lucerne. Lucerne may also promote natural enemies.

Chemical control

Trials have shown that the addition of salt (0.5% NaCl) as an adjuvant can improve chemical control of mirids at lower chemical rates.

Salt mixtures allow a reduction in chemical rate of 50–60%, which significantly reduces impact on beneficials and the risk of flaring helicoverpa.

Refer to the beneficial impact table for impact of insecticides on beneficials

Insecticide resistance has not been detected in mirids. The continual influx of mirids into cropping areas from inland regions reduces selection pressure for resistance. [40]

Consult the APVMA website for up-to-date chemical registrations.

7.10 Lucerne flea

The lucerne flea is an introduced pest commonly found in New South Wales, Victoria, Tasmania, South Australia and Western Australia. It is a green-yellow globular insect commonly found in broadleaf crops and pastures. Lucerne fleas have a furcula underneath their abdomen that acts like a spring and enables them to 'spring off' vegetation when disturbed. Synthetic pyrethroid sprays are not effective. Grazing management, border sprays or spot spraying may be sufficient to control lucerne flea populations.

Lucerne fleas (sometimes also known as clover springtails) are common pests. Higher numbers are often found in the winter rainfall areas of southern Australia, or in irrigation areas where moisture is plentiful. They are generally more problematic on loam/clay soils. Lucerne fleas are often patchily distributed within paddocks and across a region.

Damage is common and is characterised by clear membranous windows chewed into cotyledons and leaf surfaces. Early detection and control improves crop health and vigour.

The lucerne flea is a springtail; this is a group of arthropods that have six or fewer abdominal segments and a forked tubular appendage or furcula under the abdomen. Springtails are one of the most abundant of all macroscopic insects and are frequently found in leaf litter and other decaying material, where they are primarily detritivores. Very few species, including the lucerne flea, are regarded as crop pests around the world.

The adult lucerne flea is approximately 3 mm long, light green-yellow in colour and often with mottled darker patches over the body. They are wingless and have enlarged, globular shaped abdomens (Figure 9). They are not related to true fleas. Newly hatched nymphs are pale yellow and 0.5–0.75 mm long, and as they grow they resemble adults, but are smaller. [41]

40 IPM Guidelines. (2016) Mirids. http://ipmguidelinesforgrains.com.au/pests/mirids-in-soybean/

41 P Umina, S Hangartner, G McDonald (2015) Lucerne flea. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

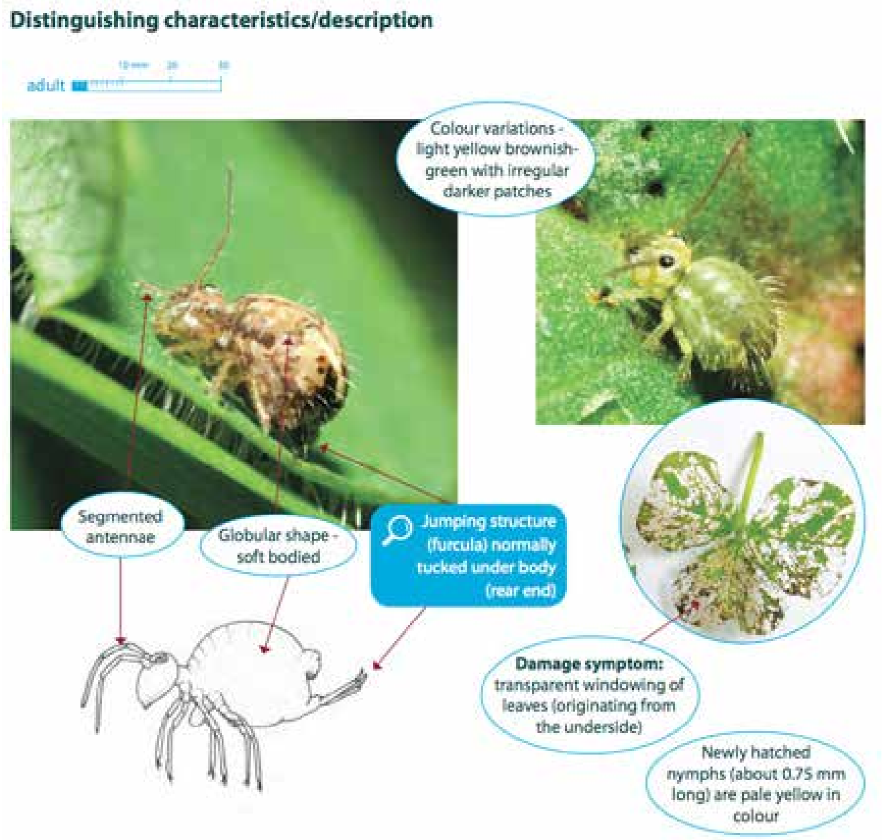


Figure 9: *Distinguishing features of the adult lucerne flea*

Source: cesar

7.10.1 Varietal resistance or tolerance

All crops and pastures, but broadleaf plants including lucerne and clover are particularly susceptible to attack. They can also cause considerable damage to lupins, canola, field peas, faba beans, ryegrass, wheat and barley. Lucerne flea also feeds on weeds including shepherd's purse, chickweed, common sow thistle and wild radish. Capeweed is a favoured weed host. [42]

7.10.2 Damage caused by Lucerne flea

Lucerne fleas move up plants from ground level, eating tissue from the underside of foliage. In lupins and canola, lucerne flea causes pitted cotyledons and chewed leaflet spots and edges (Photo 12). On other plants, they feed through a rasping process, leaving behind a thin clear layer of leaf membrane that appears as transparent 'windows' through the leaf. In severe infestations this damage can skeletonise the leaf and stunt or kill plant seedlings. Crops and pastures are most susceptible at the time of emergence. [43]

42 P Umina, S Hangartner, G McDonald (2015) Lucerne flea. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

43 P Umina, S Hangartner, G McDonald (2015) Lucerne flea. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

Photo 12: *Lupins have chewed leaflet spots and edges.*

Source: Department of Agriculture and Food, Western Australia

7.10.3 Thresholds for control

As a guide, an average of 20 small holes per trifoliate legume leaf may warrant chemical control. If pasture is severely damaged it may be cost effective to spray. [44]

7.10.4 Management of Lucerne flea

Monitoring

Crops should be inspected frequently at, and immediately following crop emergence, when plants are most susceptible to damage. Pastures should be monitored at least fortnightly from autumn to spring, and more often in paddocks with previous lucerne flea problems. Lucerne fleas are often concentrated in localised patches so it is important to monitor paddocks entirely. Examine foliage for feeding damage, and check the soil surface for sheltering insects. Damage levels can be used to determine

44 P Umina, S Hangartner, G McDonald (2015) Lucerne flea. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

whether or not spraying is necessary. Monitoring usually involves working on hands and knees. Monitoring populations for growth stage as well as numbers can also be important for accurate timing of sprays.

Alternatively, lucerne fleas can be sampled using a standard petrol powered garden blower/vacuum machine. A fine sieve or stocking is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface.

Biological control

The pasture snout mite and spiny snout mite are effective predators, particularly in pastures where they can prevent pest outbreaks. Spiders and ground beetles also prey on lucerne flea. The complex of beneficial species should be assessed before deciding on control options.

Cultural control

Grazing management by reducing the height of pasture will limit food resources and increase mortality of lucerne fleas. Control broadleaf weeds (e.g. capeweed) to remove alternative food sources that would otherwise assist in population build up. In pastures, avoid clover varieties that are susceptible to lucerne flea damage, and avoid planting susceptible crops such as canola and lucerne into paddocks with a history of lucerne flea damage.

Chemical control

In paddocks where damage is likely, a border spray may be sufficient to prevent movement of lucerne fleas into the crop from neighbouring paddocks. Lucerne fleas are often patchily distributed within crops, so spot spraying may be sufficient. Do not blanket spray unless the infestation warrants it.

If the damage warrants control, treat the infested area with an insecticide three weeks after lucerne fleas first emerge in autumn. This will allow for the further hatching of over-summering eggs but will be before they reach maturity and begin to lay winter eggs. Where there is a consistent pattern of lucerne flea damage in autumn/early winter, spray four weeks after the first significant rain of the season.

In pasture, best results are achieved by spraying when there is sufficient leaf matter for the insects to feed on and shelter under. This is usually about seven days after a paddock has been cut for hay or heavily grazed, rather than immediately after hay making or grazing.

Lucerne fleas have a high natural tolerance to synthetic pyrethroids and should not be treated with insecticides from this chemical class. When both lucerne fleas and redlegged earth mites are present, it is recommended that control strategies consider both pests, and a product registered for both is used at the highest directed rate between the two to ensure effective control. [45]

There are some pesticides registered for controlling Lucerne flea in the Northern region (Table 11). Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website for up-to-date chemical registrations.

45 P Umina, S Hangartner, G McDonald (2015) Lucerne flea. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

Table 11: *Registered products for controlling Lucerne flea in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Maldison 1169 g/L ULV	Fyfanon ULV	0.225
Omethoate* 290 g/L SL	All-Mitey 290 SL	0.1
	Le-mat 290 SL	0.1
	Mite Master 290	0.1
	Omen 290	0.1
	Omethoate 290 SL	0.1

Source: NSW DPI

Insecticide resistance in lucerne flea

Research has found a high level of tolerance to several organophosphates and/or synthetic pyrethroids in lucerne fleas. The GRDC continue to fund research into best management practices to reduce the development of insecticide resistant pest populations.

For information on management strategies, see the Insecticide resistance in RLEM section above.

7.11 Cutworm

Cutworms are caterpillars of several species of night-flying moths, one of which is the well-known bogong moth. Though they are sporadic pests, they are widely distributed across all Australian cropping regions. Winter generation moths emerge in late spring and summer. Eggs are laid onto summer and autumn weeds, where larvae can then emerge onto newly sown crops.

There are several species of pest cutworms that are all similar in appearance. Generally, larvae of all species grow to about 40–50 mm long and are relatively hairless, with a distinctly plump, greasy appearance and dark head (Photo 13 and Figure 10).

Photo 13: *Common cutworm larva in typical curled position (Source: cesar).*

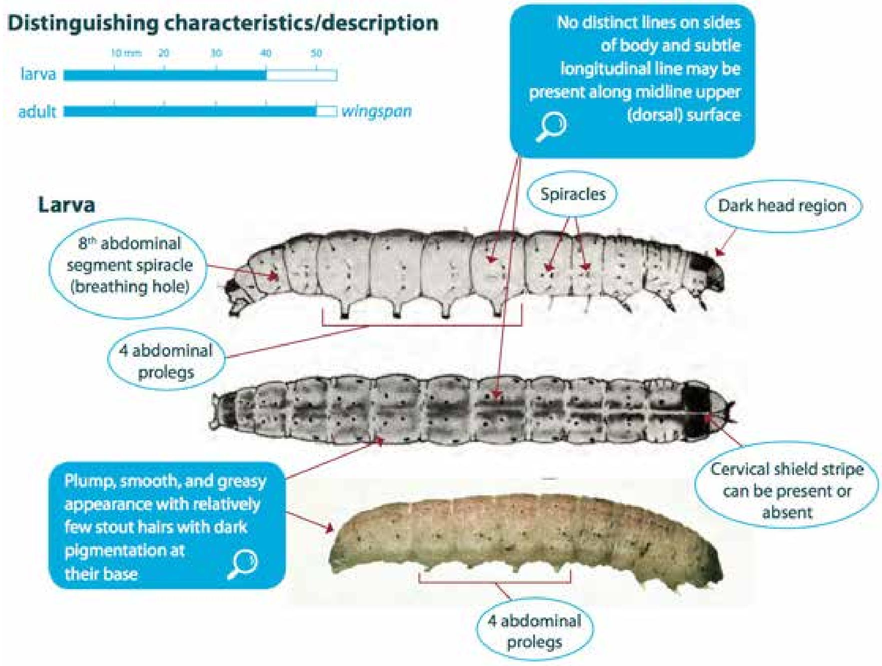


Figure 10: *Distinguishing characteristics/description of cutworms*

Source: Bellati et al. 2012

Moths of the common cutworm have dark brown or grey-black forewings with dark arrow markings on either wing above a dark streak broken by two lighter colour dots. Moths of the pink cutworm have grey-brown forewings with darker markings and streaks and a large inner light mark and darker outer mark. Moths of the black cutworm have brown or grey-black forewings with a dark arrow-mark streak broken by two dark ring-shaped dots (Figure 11).

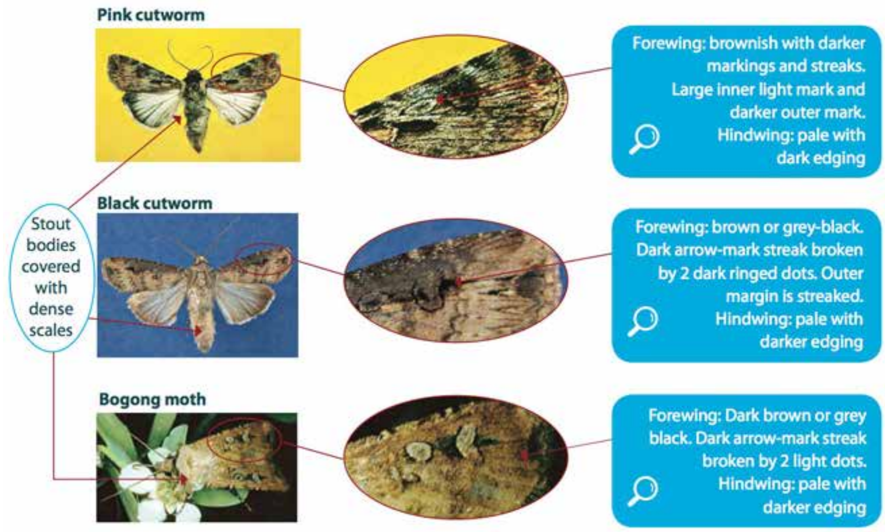


Figure 11: *Distinguishing characteristics/description of the adult forms of the pink, black and common cutworm*

Source: Bellati et al. 2012

Cutworm larvae are generally nocturnal. They hide under the soil surface, soil clods or litter and come out at night to feed, although day feeding above the ground does occur occasionally, particularly when the larvae are in high densities. Caterpillars often curl up when disturbed. During the night, adult moths are strong fliers and may be seen around lights or on window panes.

7.11.1 Damage caused by cutworms

Cutworms are a sporadic pest of all field crops and are most damaging when caterpillars transfer from summer and autumn weeds onto newly emerged seedlings.

Larvae feed at ground level, chewing through leaves and stems. Stems are often cut off at the base, hence the name 'cutworm'. Winter crops are most susceptible in autumn and winter, although damage can occur throughout the year, especially in irrigated crops. Damage mostly occurs at night when larvae are active. When numbers of larvae are high, crops can be severely thinned (Photo 14). Smaller larvae can cause similar damage to lucerne flea when they feed on leaf surface tissue. Young plants are favoured and are more adversely affected than older plants.

Occasionally another undescribed genus of caterpillars marked with a herringbone pattern on their abdomen inflict cutworm-like damage on emerging crops.

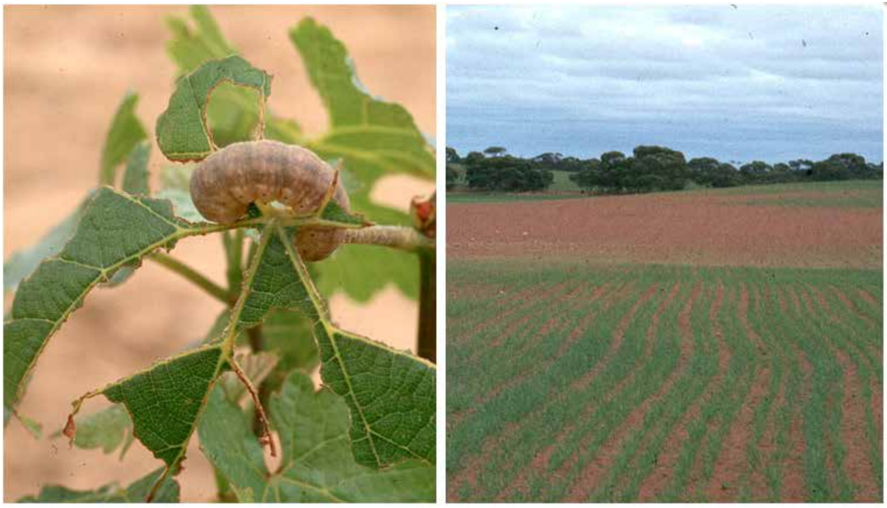


Photo 14: *Pink cutworm damage*

Source: SARDI

7.11.2 Thresholds for control

Treatment of cereals and canola is warranted if there are two or more larvae per 0.5 m of row [46] e.g. 1–2 cutworms per square metre. This threshold can also be applied to lupin.

7.11.3 Management of cutworm

Key IPM strategies for cutworms in the Northern region:

- Pre-season
  - » Control weeds hosts in fallow and in paddocks at least 2 weeks prior to sowing to minimise risk of larvae moving onto crop.
- Pre-sowing
  - » Monitor crop edges, especially adjacent to weedy fallows and roadsides as cutworm may move following a herbicide application.
- Emergence
  - » Monitor for leaf and seedling damage. Larvae feed at night and shelter at the base of plants during the day.
- Crop establishment

46 S Hangartner, G McDonald, P Umina. (2015). PestNotes: Cutworm. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cutworm

» Very occasionally cutworm will damage older seedlings. [47]

Monitoring

Check crops from emergence through to establishment. Look for patchy areas or parts of the crop that have been thinned. Larvae are mostly nocturnal but some species might be found feeding in the late afternoon. During the day they hide under clods of soil or bury themselves in the soil. Check the base of recently damaged plants, and healthy surrounding plants, by scratching the soil to reveal hidden larvae. [48]

Biological control

Naturally occurring insect fungal diseases that affect cutworms can reduce populations. Wasp and fly parasitoids, including the orange caterpillar parasite (*Netelia producta*), the two-toned caterpillar parasite (*Heteropelma scaposum*) and the orchid dupe (*Lissopimpla excelsa*) can suppress cutworm populations. Spiders are generalist predators will also prey upon cutworms.

Cultural control

As autumn cutworm populations may be initiated on crop weeds or volunteers in and around the crop, removal of this green bridge 3–4 weeks before crop emergence will remove food for the young cutworms. [49]

Chemical control

If required, cutworms can be easily controlled with insecticides. Several chemicals are registered for controlling cutworms, depending on the state and crop of registration (Table 12). Spot spraying often provides adequate control in situations where cutworms are confined to specific regions within paddocks. Spraying in the evening is likely to be more effective as larvae are emerging to feed and insecticide degradation is minimised.

Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website for up-to-date chemical registrations.

Table 12: *Registered products for controlling Cutworm in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Alpha-cypermethrin* 100 g/L EC 250 g/L SC	Alpha-Scud Elite	75 mL
	Astound Duo	75 mL
	Dictate 100	75 mL
	Dominex Duo	75 mL
	Fastac Duo	75 mL
	Alpha Forte 250 SC	30 mL
Beta-cyfluthrin 25 g/L EC	Bulldock Duo	0.2 or 0.4
Cypermethrin* 200 g/L EC	Cypershield 200 Scud Elite Titan Cypermethrin 200	75 mL

47 IPM Guidelines. (2014). 'Best Bets' IPM Strategies for establishment pests in the Northern region. http://ipmguidelinesforgrains.com.au/wp-content/uploads/BestBet_EstablishmentNorth2014.pdf

48 S Hangartner, G McDonald, P Umina. (2015). PestNotes: Cutworm. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cutworm

49 S Hangartner, G McDonald, P Umina. (2015). PestNotes: Cutworm. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cutworm

Chemical formulation	Registered trade names	Application (litres per ha)
Deltamethrin* 27.5 g/L EC	Ballistic Elite	0.2
5.5 g/L ULV	D-Sect EC	0.2
	decis options	0.2
	Deltaguard ULV	1.0

*Numerous other generic products are also registered.

Source: NSW DPI

7.12 Native budworm of Heliothis (*Helicoverpa* sp.)

Native budworm (*Helicoverpa* sp.) caterpillars are a major annual pest of lupin flowers and crops. [50]

Two species of helicoverpa are serious pests of field crops (particularly grain legumes, summer grains and cotton) in the northern grains region of Australia. *Helicoverpa armigera* is generally regarded as the more serious pest because of its greater capacity to develop resistance to insecticides, broader host range, and persistence in cropping areas from year to year.

Helicoverpa puntigera is a native species that is common and widely distributed throughout Australia. Native budworm breeds over winter in the arid inland regions of Queensland, New South Wales, South Australia and Western Australia on desert plants before migrating into southern agricultural areas in late winter or spring.

Helicoverpa eggs can be found singly on the growing tips and buds of plants. They are small (about 0.5 mm in diameter) but quite visible to the naked eye after close inspection of the plant. They are white when first laid but change colour from yellow through to brown/black, as they get closer to hatching (Figure 12).

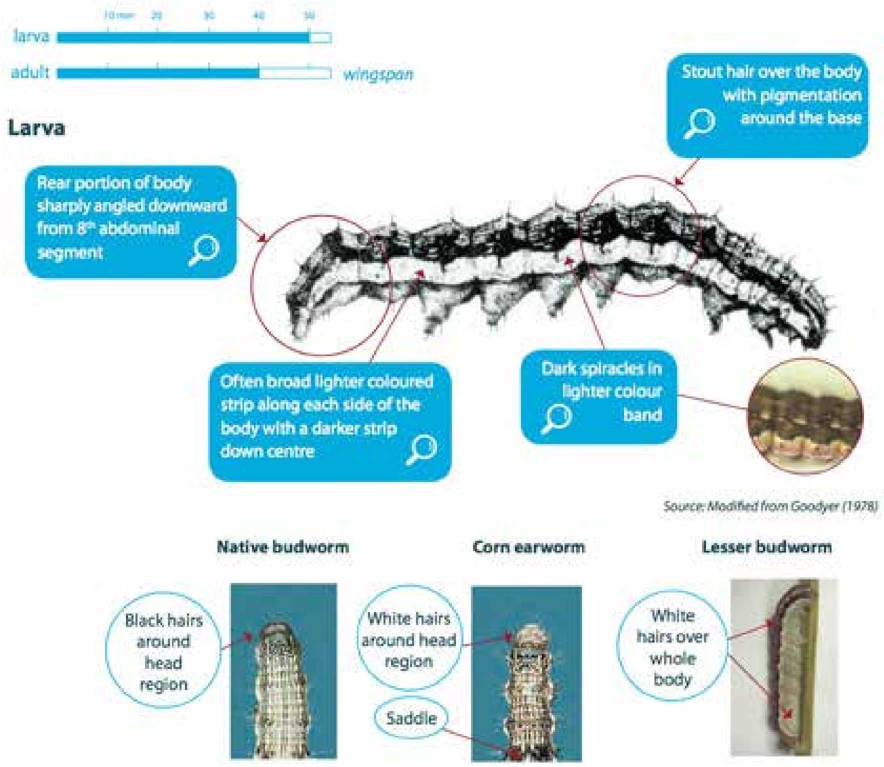


Figure 12: *Distinguishing characteristics/description of native budworm*

Source: Bellati et al. 2012

50 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Newly hatched caterpillars (larvae) are very small (approximately 1.5 mm), light in colour with dark brown heads. They can easily be missed when inspecting a crop. They will grow through six or seven stages or instars until reaching maturity (up to 40 mm long).

Larvae vary substantially in colour that includes shades of brown, green and orange. Regardless of colour, they usually have darkish stripes along the body and bumpy skin with sparse, stiff, stout hairs (Photo 15). One distinguishing feature of *Helicoverpa* larvae is the sharp downward angling at the rear of the body.

Photo 15: *H. armigera larvae (left) and H. puntigera larvae (right).*

Source: IPM Guidelines

Native budworms breed during winter on flowering plants in inland Australia when there is sufficient rainfall for broadleaf vegetation to flourish. When this inland vegetation dies off, typically in late winter/spring, the larvae pupate and moths emerge in readiness to migrate, often to the southern and eastern agricultural regions. Migratory moths reach the cropping areas by flying vertically up into the warm northerly or northwesterly winds that precede cold fronts in the winter/ spring period. Hence, the moths that are frequently encountered in crops during early spring may well have had their origins from somewhere in the inland of Australia.

Moths (Figure 13) typically lay up to 1000 white spherical eggs singularly near the top of growth points of the plant. Eggs darken as they mature and larvae hatch in 7–14 days. *Helicoverpa* larvae develop through six growth stages, becoming fully-grown in 2–3 weeks in summer and 4–6 weeks in spring. They will generally have four to five generations per season. Larval activity increases in warmer conditions, and ceases when temperatures fall below about 12°C.

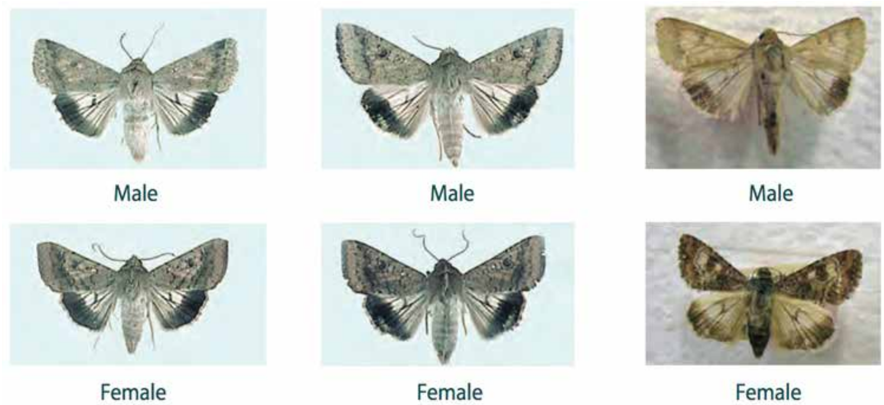


Figure 13: *Distinguishing characteristics/description of Helicoverpa*

Source: Bellati et al. 2012

Early instar larvae, less than 7 mm, generally feed on leaves, or graze on the surface of pods. Exceptions can be following periods of unseasonably warm when even very small larvae burrow into young pods, making them difficult to monitor.

A notable feature of this pest is its capacity to migrate at high altitudes over large distances (100–1000 km) at night. The moths fly from areas where conditions do not favour another generation to where there are abundant food plants for further breeding.

Moths live for two to four weeks; they rest during the day and become active after sunset, feeding on nectar from flowers and laying eggs on many types of herbaceous plants (weeds and crops). They fly rapidly from plant to plant throughout the night in a darting motion, feeding and laying eggs; this behaviour is often used to recognise budworm moths. They are also capable of flying from paddock to paddock and of course, from one region to another.

7.12.1 Varietal resistance or tolerance

Helicoverpa attack pulse crops such as lupins, field peas**,** faba beans, lentils, chickpeas and soybeans, as well as canola, lucerne, sunflower, safflower, annual medic and clovers.

7.12.2 Damage caused by *Helicoverpa*

Native budworm can cause damage from flowering to early pod filling, however, they are at their most damaging when they feed on the fruiting parts and seeds of plants. Small caterpillars (1 to 5 mm) feed inside the flowers. Larvae feed on leaves, stems and pods and, when big enough, they burrow into pods and feed on the developing seed. Narrow-leafed lupin crops will not be damaged until they are close to maturity and the pods are losing their green colouration. Pod walls are not penetrated until the caterpillars are over 15 mm long. Large caterpillars (25 mm) eat holes in the pods and seeds (Photo 16). [51]

Photo 16: *Caterpillar damage to lupin pods.*

Photo: Ray Cowley, Source: NSW DPI

Holes or chewing damage may be seen on pods and/or seed heads (Photo 17). Grubs may be seen or may remain embedded in the pod. Losses attributed to budworms come from direct weight loss through seeds being wholly or partly eaten.

Caterpillars eat increasing quantities of seed and plant material as they grow. The last two growth stages (5th & 6th instar) account for over 90% of their total grain consumption.

51 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 17: *Damage to albus lupin seeds caused by helicoverpa.*

Source: Lowan Turton,

Source: NSW DPI

Apart from yield loss, premium downgrades are also a possibility because of budworm damage. The large seeded pulses are particularly susceptible to being downgraded through receival standards at the silo because of nibbled or defective grain. Partial seed damage is more likely than in smaller seeded pulses.

7.12.3 Thresholds for control

Comprehensive and dynamic economic thresholds have been developed for *H. puntigera*. Human consumption markets have strict limits on insect-damaged seeds, so populations of 1–2 larvae per square metre warrant control.

Below is an example, assuming cost of control at $10/ha (Table 13). Control is warranted if the cost of control is less than the value of the yield loss predicted.

Table 13: *Yield loss estimates for five pulses and corresponding economic thresholds (ET) for native budworm. Source: (Mangano et al. 2006) in cesar*

	K – grain loss kg/larva/ha	P – grain price $/tonne	C – cost of control $/ha	ET – larvae per 10 sweeps*
Field peas	50	400	10	0.5
Lentils	60	680	10	0.3
Faba bean	90	500	10	0.2
Chickpeas - desi	30	600	10	0.6
Canola	6	450	10	4.0
Lupins	7	420	10	4.0

* Numbers exclude very small larvae.

Estimates using other grain price and control costs can be estimated by applying the formula: ET = (C x 1000) / (K x P).

Based on these values, 3.4 larvae per 10 sweeps warrants control in lupin.

The threshold for control is high in lupin and canola, but for most pulses the economic threshold for control is below 1 larva per 10 sweeps. [52]

For *H. armigera*, control is warranted in Lupins in NSW at:

- Flowering- podfilling:
  - » Albus lupins for human consumption: 1- 2 larvae per m^2 (<5 mm long) or per 10 sweeps
  - » Stockfeed: 1–2 larvae per 10 sweeps. [53]

7.12.4 Management of Helicoverpa

Monitoring

Occurrence is common and control decisions should be based on regular monitoring. Crops should be monitored twice weekly once flowering has started.

Sweep with a 38 cm diameter net 10 times in at least five different areas of the crop. Delay spraying until the majority of larvae are about 1 cm long. Spraying too early increases the risk of a second population developing before harvest. Do not delay too long though because larger caterpillars require higher rates of insecticide and are the ones that bore into pods, causing the greatest economic losses.

A beatsheet can also be used to monitor pest incidence. If 1–2 larvae are found per square metre, control is warranted.

The use of pheromone traps (which attract male moths) provides an early warning of moth arrival and abundance, following their migration from inland regions. These should be set up in late winter or early spring.

Biological control

A key component to any IPM is to maximise the number of beneficial organisms and incorporate management strategies that reduce the need for pesticides. Correct identification and monitoring is the key when checking for build up or decline in beneficials. There are many natural enemies that attack native budworm. The egg stage is susceptible to the parasite *Trichogramma ivalae*, a minute wasp that has been recorded in up to 60% of eggs along with egg predators such as ladybird beetles, lacewings and spiders. Beneficials attacking larvae include shield bugs, damsel bugs, assassin bugs, tachinid flies (their larvae prey on caterpillars), orange caterpillar parasite, two-toned caterpillar parasite, orchid dupe, lacewings and spiders. Naturally occurring fungal diseases and viruses also play an important role in some seasons.

Cultural control

Cultivating and slashing can reduce pupal and larvae survival. In northern areas of the Northern region, chickpeas can be used as a trap crop to capture overwintering populations merging from diapause. Avoid successive plantings of summer legumes. Weed management in and around crops can prevent the build-up of corn earworm and other insect pests.

Chemical control

There are several insecticides registered for the control of native budworm (Table 14). Timing and coverage are both critical to achieving good control. Try to target small larvae up to 7 mm in length and apply insecticides before larvae move into flowering pods. IPM options include the use of Bt (*Bacillus thuringiensis*) and nuclear polyhedrosis virus (NPV) based biological insecticides. Small larvae are generally easier to control because they are more susceptible to insecticides, and leaf feeding makes them susceptible to ingestion of active residues on the plant surface. Larvae

52 G MacDonald. (2015). PestNotes: Native budworm. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Native-budworm

53 P Umina, S Hangartner, G McDonald (2015) Corn earworm. cesar. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Corn-earworm

entrenched in buds and pods will be more difficult to control and chemical residual will be important in contacting them.

Aerial insecticide application is often required.

In choosing a registered product, be aware of the withholding period for harvest or windrowing which is the same as harvest. Residue testing is routinely conducted on grain destined for export and domestic stock feed markets. [54]

Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website for up-to-date chemical registrations.

The crop should be re-inspected 2 to 4 days after spraying to ensure enough caterpillars have been killed to prevent future damage and economic loss. In years of very high moth activity and extended egg lays, a second spray may be required.

Table 14: *Registered products for controlling Helicoverpa in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Alpha-cypermethrin* 100 g/L EC 250 g/L SC	Alpha-Scud Elite	0.2 or 0.3[1]
	Astound Duo	0.2 or 0.3[1]
	Dictate 100	0.2 or 0.3[1]
	Dominex Duo	0.2 or 0.3[1]
	Fastac Duo	0.2 or 0.3[1]
	Alpha Forte 250 SC	80 or 120 mL
Bacillus thuringiensis sub-species kurstkai	Bi°Crystal	0.5–2.0
	DiPel SC	1.0–4.0
Beta-cyfluthrin 25 g/L EC	Bulldock Duo	0.2 or 0.4[1]
Cypermethrin* 200 g/L EC	Cypershield 200	0.2 or 0.3[1]
	Scud Elite	0.2–0.3[1]
	Titan Cypermethrin 200	0.2–0.3[1]
Deltamethrin* 27.5 g/L EC	Ballistic Elite	0.2–0.5[4]
5.5 g/L ULV	D-Sect EC	0.5
	decis options	0.2–0.5[4]
	Deltaguard ULV	2.5
Esfenvalerate 50 g/L EC	Sumi-Alpha Flex	0.13–0.33[67]
Gamma-cyhalothrin 150 g/L CS	Trojan	20 mL[7]
Lambda-cyhalothrin 250 g/L CS	Flipper 250 CS	24 mL[7]
	Karate (Zeon Tech)	24 mL[7]
	Kung Fu 250	24 mL[7]
	Matador (Zeon Tech)	24 mL[7]
Methomyl 225 g/L SL	Electra 225	1.5–2.0[10]
	Lannate L	1.5–2.0[10]
	Marlin	1.5 or 2.0
	Methomyl 225	1.5 or 2.0**
	Nudrin 225	1.5–2.0**

54 G MacDonald. (2015). PestNotes: Native budworm. cesar. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Native-budworm

Chemical formulation	Registered trade names	Application (litres per ha)
Nuclear polyhedrosis virus (NPV) 2 thousand million/mL (Obs)	Gemstar LC	0.375
	Vivus Gold	0.375
	Vivus Max	0.15

*Numerous other generic products are also registered.
1 Registered for native budworms (*Helicoverpa punctigera*) only.
4 Registered for corn earworms (*Helicoverpa armigera*) at 0.5 L/ha.
6 Registered in southern NSW only.
7 Registered for native budworms (*Helicoverpa punctigera*) only
10 Registered for native budworm (Helicoverpa punctigera) only
**Also registered as an ovicide for heliothis at 0.5–1.0 L/ha.

Source: NSW DPI

Insecticide resistance in Helivocerpa

Without large-scale migrations of *H. armigera* from unsprayed areas of 'outback' native vegetation to dilute localised resistant populations, the phenomenon of insecticide resistance compounds rapidly.

An insecticide Resistance Management Strategy (IRMS) has been development to reduce the risk of resistance in *Helicoverpa*. The IRMS aims to ensure that there is a sufficient break, of at least one *Helicoverpa* generation, in the use of each insecticide group, across all crops.

Currently there are no restrictions on the number of pyrethroid sprays that can be applied to non-cotton crops, but there are a number of considerations that apply to the use of pyrethroids in the farming systems.

It is strongly recommended that pyrethroids not be used on *Helicoverpa armigera*, as they are unreliable.

Pyrethroids should be targeted only on small larvae (i.e. less than 7 mm long) as application on larger resistant larvae will be ineffective and will increase levels of pyrethroid resistance. (Note: even for insecticide groups for which resistance is not established, small larvae are still more susceptible than larger larvae).

If growers are intending to spray a population of *Helicoverpa*, consider where the moths that laid the eggs may have originated. If they are likely to be survivors from a crop that was previously sprayed (e.g. with a pyrethroid), spraying again with the same insecticide will exacerbate resistance.

Avoid using broad-spectrum sprays such as organophosphates or pyrethroids early in the season. They reduce the numbers of beneficial insects and increase the chances of aphid, mite and further *Helicoverpa* outbreaks.

The use of ovicides may be warranted in the event of high egg pressure - use methomyl before the black-head egg stage.

Use recommended larval thresholds to minimise pesticide use and reduce resistance selection. Sprays should only be applied if the larvae are doing economic damage (i.e. the value of the crop saved should exceed the cost of spraying).

Cultivate chickpea and other host-crop residues as soon as possible after harvest to destroy pupae. Cultivation must be completed no later than one month after large larvae were observed in the field, otherwise the moths will emerge and move elsewhere.

Do not respray an apparent failure with a product of the same chemistry. [55]

55 DAF Qld (2011) Helicoverpa and insecticide resistance. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/helicoverpa/insecticide-resistance

7.13 Armyworm

Armyworms are common caterpillar pests mostly of grass pastures, cereal and rice crops, and they can sometimes attack lupin crops. The larvae are identifiable by three parallel white stripes along their body. They cause most damage to crops through defoliation in autumn and winter, but can also cause direct seed loss in spring and summer. In the uncommon event of extreme food depletion and crowding, they will 'march' out of crops and pastures in plague proportions in search of food, which gives them the name 'armyworm'.

These are native pests. Common armyworm (Leucania convecta) is found in all states of Australia and potentially will invade all major broadacre-cropping regions year round, but particularly spring and summer. The Persectania species are more typically found in southern regions of Australian autumn and winter, but their activity can sometimes extend into spring. The three armyworm species commonly found are the common, southern and inland armyworms. Note that the common armyworm, *Leucania convecta*, was formally known as *Mythimna convecta*. They are difficult to distinguish apart, however, correct species identification in the field is generally not critical because their habits, type of damage and control are similar.

Armyworm caterpillars of all species are about 1 mm long after hatching and grow up to 40 mm in length and usually have smooth bodies with a few fine hairs. Body colour can vary, but larvae are generally green, brown or yellow with three parallel white longitudinal stripes running from the 'collar' behind the head, along the body to the tail end (Figure 14). The body stripes can vary, but the collar stripes are always present. They have one pair of anal prolegs and four pairs of abdominal prolegs. Larvae live and pupate in the soil and are generally nocturnal.

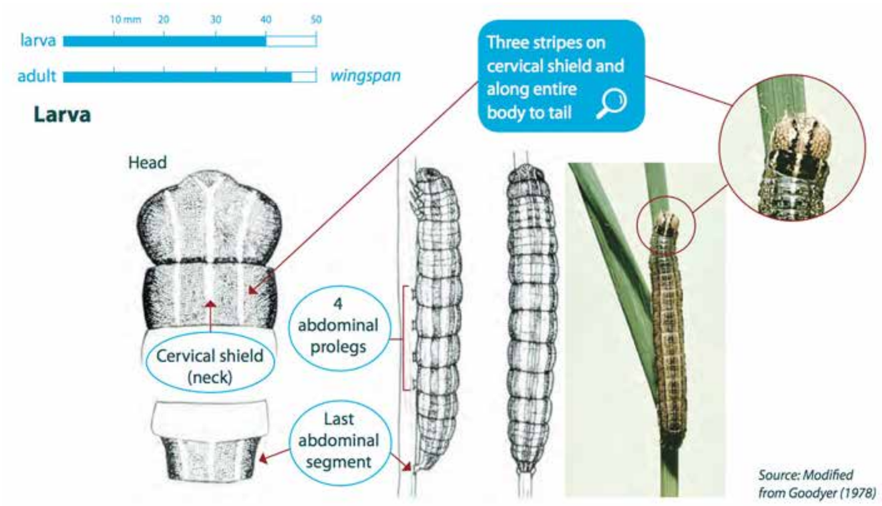


Figure 14: *Distinguishing characteristics and description of armyworm caterpillars.*

Source: cesar

Adult moths are grey-brown in colour and have a stout body with a wingspan of approximately 40–45 mm (Figure 15). The common armyworm migrates into south-eastern Australian cropping areas in late winter or early spring laying eggs in cereals, rice and pastures. Southern and inland armyworms, which are also migratory, are most commonly found in autumn and winter, often in relatively high densities. They can also be found damaging crops during spring in cooler regions. All armyworms lay eggs in dry grass and stubble from previous cereal crops or pasture. [56]

56 G McDonald (2016) Armyworm. cesar. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Armyworm

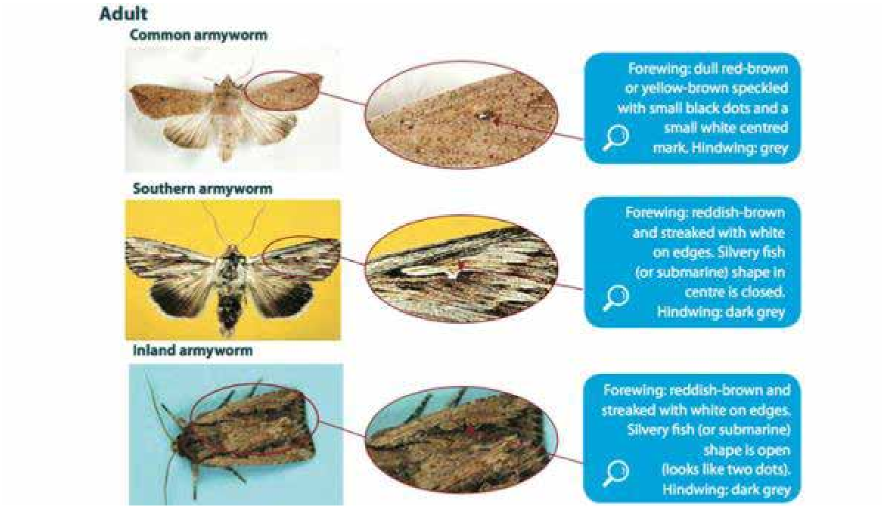


Figure 15: *Distinguishing characteristics/description of armyworms*

Source: Bellati *et al.* 2012

7.13.1 Varietal resistance or tolerance

Armyworm is rarely a problem in lupin, however, there have been reports on damage in the Southern region. [57]

7.13.2 Damage caused by armyworm

There are two periods of armyworm damage: late autumn and winter (low to moderate economic damage) and late spring (high risk of seed loss in maturing crops). Armyworm larvae feed on the leaf margins of seedling and vegetative crops causing 'scalloping'. Larger larvae consume greater volumes of leaves, and seedlings and early vegetative crops may be completely defoliated.

Damaging infestations in autumn and winter are almost always associated with crops sown into standing stubble, providing a medium upon which moths lay their eggs. [58]

7.13.3 Thresholds for control

There are no economic threshold for control in lupin as they are rarely at damaging levels.

In other crops, in spring outbreaks (during crop ripening) spraying is recommended when the density of larvae exceeds 1 to 3 larvae per m^2 although this figure must be interpreted in light of timing of harvest, green matter available in the crop, expected return on the crop, and larval development stage. [59]

7.13.4 Management of armyworm

Monitoring

Early in the season, monitor crops sown into standing stubble, as this is commonly where armyworm damage will appear first.

When crops are approaching ripening, early detection of armyworm is important. The most critical time is 3–4 weeks prior to harvest. Assessing the numbers of armyworms can be difficult because their movements vary with weather conditions and feeding preferences. Larvae are most active at night, although can sometimes be seen during

57 Cesar Australia (2016) PestFacts Issue No. 7 – 19th August 2016. http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2016–2/pestfacts-issue-no-7-19th-august-2016/partners-in-crime-update-on-armyworms-and-herringbone-caterpillars/

58 G McDonald (2016) Armyworm. cesar. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Armyworm

59 G McDonald (2016) Armyworm. cesar. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Armyworm

the day feeding on leaves and stems of crops. Look for signs of caterpillar droppings (frass) and damage to plant heads. Look for caterpillars on plants and on the ground, especially under leaf litter between the rows. Check frequently for signs of head-lopping in barley, oats and rice.

There are several techniques for monitoring armyworm; a) use of a sweep net in a crop, particularly in the early evening, provides an indication of the relative densities and stages of armyworm; b) A beatsheet sampling provides a better absolute measure; and c) ground searching. Although more time consuming, ground searches provide the best indication of the imminent damage potential of large larvae. [60]

Biological control

Parasitic flies and wasps, predatory beetles and diseases commonly attack armyworms, and can suppress natural populations, particularly in spring, if not disrupted by broad-spectrum insecticides. Parasitoids and beetles attack early stage larvae while late stage caterpillars and pupae commonly succumb to parasitic flies and wasps. [61]

Cultural control

Control weeds to remove alternative hosts. Armyworm often feed on ryegrass before moving into crops.

Standing stubble from previous crops, dead leaves on crops and grassy weeds are suitable sites for female armyworm to lay eggs.

Larvae can move into cereals if adjacent pastures are chemically fallowed, spray topped or cultivated in spring. Monitor for at least a week post treatment. Damage is generally confined to crop margins. [62]

Chemical control

There are several insecticides registered against armyworms in broadacre crops (Table 14). See the APVMA website for current chemical options.

The biological insecticide *Bacillus thuringiensis* (Bt) is effective on armyworms and is also 'soft' on natural enemies. Spray *Bt* late in the day/evening to minimise UV breakdown of the product, and ensure the insecticide is sprayed out within 2 hours of mixing. Make sure the appropriate strain is used for the target pest, add a wetting agent and use high water volumes to ensure good coverage on leaf surfaces. When insecticides are required, it is recommended that applications be carried out in the late afternoon or early evening. [63]

Table 15: *Registered products for controlling armyworm in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Alpha-cypermethrin* 100 g/L EC 250 g/L SC	Alpha-Scud Elite	0.24
	Astound Duo	0.24
	Dictate 100	0.24
	Dominex Duo	0.24
	Fastac Duo	0.24
	Alpha Forte 250 SC	96 mL
Bacillus thuringiensis sub-species kurstkai	Bi°Crystal	0.5–2.0
	DiPel SC	1.0–4.0

*Numerous other generic products are also registered.

Source: NSW DPI

60 G McDonald (2016) Armyworm. cesar. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Armyworm

61 G McDonald (2016) Armyworm. cesar. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Armyworm

62 IPM Guidelines (2016) Armyworm. http://ipmguidelinesforgrains.com.au/pests/armyworm/

63 G McDonald (2016) Armyworm. cesar. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Armyworm

7.14 Loopers

There are a number of looper species that can impact crops in the Northern region. Brown pasture loopers are one of the more common species, however they are only occasional pests to various crops. The loopers are relatively large, dark coloured native caterpillars with a characteristic looping motion. Loopers are an irregular minor pest that is native and widely distributed throughout Australia, except in the Northern Territory. They are more prevalent in high rainfall districts.

Damage is more likely to occur in autumn and winter when large caterpillars march from summer and autumn weeds onto newly emerged crop seedlings. Damage can be reduced by natural predators and controlling summer and autumn broadleaf weeds, particularly capeweed and stocksbill. If needed, there are several insecticides registered against brown pasture loopers, although spot spaying or perimeter spraying is usually all that is required.

Brown pasture looper larvae are dark brown to grey with a distinctive wavy yellow line along the back either side of a conspicuous dark band. They have red colouration surrounding the breathing holes (spiracles) along the sides of the body, and can grow to 20–35 mm in length (Photo 18). They use their single pair of abdominal prolegs and one pair of anal prolegs to move using a series of back arches, which results in a characteristic looping motion.[64]

Photo 18: *Brown pasture looper larvae showing the abdominal and anal prolegs (left) and the two yellow lines running along its back (right)*

Source: cesar

7.14.1 Varietal resistance and tolerance

Lupins, canola and lucerne as well as broadleaved-weed component of pastures can be attacked by loopers.[65]

7.14.2 Damaged caused by loopers

Larvae attack pastures, canola and some pulse crops, and are most damaging when caterpillars are greater than 20 mm long. They usually cause damage when they migrate from summer and autumn weeds onto newly emerged seedlings. Feeding damage to leaves and severe defoliation can occur.[66]

7.14.3 Thresholds for control

There are no economic thresholds established for this pest.[67]

64 S Hangartner, G McDonald (2015) Brown Pasture Loopers. PestNotes cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Brown-pasture-looper

65 S Hangartner, G McDonald (2015) Brown Pasture Loopers. PestNotes cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Brown-pasture-looper

66 S Hangartner, G McDonald (2015) Brown Pasture Loopers. PestNotes cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Brown-pasture-looper

67 S Hangartner, G McDonald (2015) Brown Pasture Loopers. PestNotes cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Brown-pasture-looper

7.14.4 Management of loopers

Biological

Brown pasture looper eggs can be attacked by wasp caterpillar parasitoids.

Spined predatory shield bugs and glossy shield bugs attack young larvae.

Cultural

Control summer and autumn broadleaf weeds (in particular capeweed and storksbill (*Erodium* spp.) within paddocks and along fencelines.

Chemical

There are several insecticides registered against brown pasture loopers in pastures and various broadacre crops (Table 16). Spot spraying or perimeter- spraying is usually all that is required as this pest often moves from weedy perimeters (e.g. fencelines) into crops. [68]

Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website for up-to-date chemical registrations.

Table 16: *Registered products for controlling Loopers in lupins in the Northern region.*

Chemical formulation	Registered trade names	Application (litres per ha)
Bacillus thuringiensis sub-species kurstkai	Bi°Crystal	0.5–2.0
	DiPel SC	1.0–4.0
Bifenthrin 100 g/L EC	Arrow 100 EC[3]	50–100 mL
	Bifenthrin 100 EC[3]	50–100 mL
	Ospray Bifenthrin 100 EC[3]	50–100 mL
	Talstar 100 EC3	50–100 mL
Deltamethrin* 27.5 g/L EC	Ballistic Elite	0.5
5.5 g/L ULV	D-Sect EC	0.5
	decis options	0.5
	Deltaguard ULV	2.5
Lambda-cyhalothrin 250 g/L CS	Flipper 250 CS	12 mL
	Karate (Zeon Tech)	12 mL
	Kung Fu 250	12 mL
	Matador (Zeon Tech)	12 mL

*Numerous other generic products are also registered.

Source: NSW DPI

7.15 Lucerne seed web moth (Etiella)

Lucerne seed web moths have a protruding beak and a distinctive white stripe along the edge of the forewing. The risk period is when pods are green. Dry pods are not at risk.

The lucerne seed web moth, also referred to as '*Etiella*', is widespread throughout Australia. Although they only occur sporadically, when present they are potentially a very serious pest of agricultural crops in New South Wales, Queensland, Western Australia, South Australia and Victoria.

68 S Hangartner, G McDonald (2015) Brown Pasture Loopers. PestNotes cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Brown-pasture-looper

Adult moths are 10–15 mm long, greyish-brown in colour and when at rest they are long and slender in appearance. They have a tan coloured band that runs across the forewings and a white strip that runs the full length along the outer edge of the forewings. Moths also have a snout-like beak, which protrudes forward from the head (Figure 16). Eggs are clear in colour and change to orange prior to hatching.

Early instar larvae are pale green or sometimes cream, with distinctive pink stripes along their body. As larvae mature they become pinker in colour and the stripes redden. Larvae have four pairs of abdominal prolegs and one anal proleg. They grow up to 12 mm long. Younger larvae have dark brown head capsules, but as they mature this turns to a light brown colour. [69]

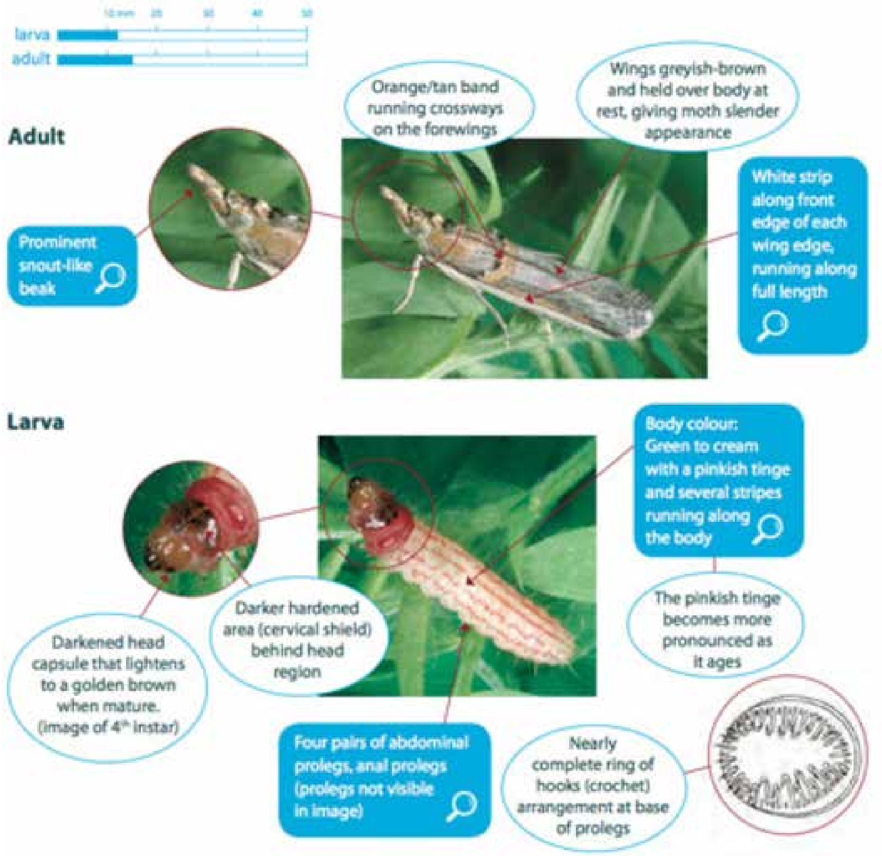


Figure 16: *Distinguishing characteristics/description of the lucerne seed web moth*

Source: Bellati et al. 2012

7.15.1 Varietal resistance or tolerance

Lucerne seed web moth predominantly attacks lentils and lucerne, but can also be found in lupins, field peas, peanuts, soybeans, vetch, medics and clovers. [70]

7.15.2 Damage caused by pest

Shortly after larvae hatch they bore into seedpods, which creates small 'pin-holes'. As the larvae develop they feed on the seed causing seed damage and yield losses. Mature larvae will damage more than one single pod and have the ability to web seedpods together to continue their feeding regime. Major damage caused by larvae

69 P Umina, B Kimber (2015) Lucerne seed web moth or Etiella. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-seed-web-moth-or-Etiella

70 P Umina, B Kimber (2015) Lucerne seed web moth or Etiella. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-seed-web-moth-or-Etiella

is indicated by the jagged remains of eaten seeds and quantities of frass in pods (Photo 19). [71]

Photo 19: *Etiella larva in a pulse pod with damaged seeds (left) and larva and damaged seed showing larval frass (right)*

Source: SARDI

7.15.3 Thresholds for control

An indicative threshold for lentils is 2 or more adult moths per 20 sweeps. In lucerne, control may be warranted if about 5% of seed pods contain small larvae. [72] No economic thresholds have been established for lupin, however the above values may be used to help decision making. Etiella does not usually cause economic damage in lupin unless there are plant hosts such as lucerne growing nearby over summer.

7.15.4 Management of Etiella

Monitoring

Start to monitor crops in spring during early pod development. This will coincide with the first moth flights, which usually take place during September. There are various monitoring tools:

- Use the degree-day model produced by SARDI to help identify the predicted onset of moth flights and when critical crop monitoring will be required. (The model requires that you add local maximum and minimum temperatures, beyond June 21st, to the spreadsheet).
- Use pheromone traps to monitor moth flights in paddocks by a placing a minimum of two traps 25 cm above the crop. Light traps are another means of monitoring moth numbers.
- A sweep-net can be used to monitor larval activity, and seedpods should be checked visually for the presence of grubs. A minimum of three groups of 20 sweeps taken randomly across the paddock will be required to accurately check for pest activity.

Biological control

There are several parasitic wasps and flies that attack the larvae of lucerne seed web moths. Predatory bugs such as the glossy shield bug and predatory shield bug also prey upon larvae.

71 P Umina, B Kimber (2015) Lucerne seed web moth or Etiella. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-seed-web-moth-or-Etiella

72 P Umina, B Kimber (2015) Lucerne seed web moth or Etiella. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-seed-web-moth-or-Etiella

Cultural control

Time of sowing and variety selection (early maturing varieties) can result in crops flowering and setting pods prior to peak activity of lucerne seed web moths. Control volunteer legumes and other host plants to prevent population development.

Chemical control

There are several insecticides registered against lucerne weed web moth. Monitor early, as insecticides will only control larvae present on the outside of pods. Check for webbing in flowers and growing point of the plant. Once eggs have been laid and larvae have bored into seed pods, insecticide applications are mostly ineffective as the larvae are protected from contact sprays.[73]

Before chemical control measures are taken, take consideration of withholding periods and ensure to check labels and recommendation. Consult the APVMA website for up-to-date chemical registrations.

7.16 Wireworms and false wireworms

Wireworms and false wireworms are common, soil-inhabiting pests of newly sown winter and summer crops. Wireworms are the larvae of several species of Australian native beetles which are commonly called click beetles. False wireworms are also the larval form of beetles, some of which are known as pie-dish beetles, which belong to another family, Tenebrionidae, and have distinctively different forms and behaviour.

Both groups inhabit native grassland and improved pastures where they generally cause little damage. However, cultivation and fallowing decimate their food supply, so any new seedlings that grow may be attacked and sometimes destroyed. They attack the pre-emergent and post-emergent seedlings of all oilseeds, grain legumes and cereals, particularly in light, well-draining soils with a high organic content. Crops with fine seedlings, such as canola and linola, are most susceptible.

The incidence of damage caused by wireworms and false wireworms is increasing with increasing use of minimum tillage and short fallow periods.

7.16.1 False wireworms

False wireworms are the larvae of native beetles which normally live in grasslands or pastures and cause little or no damage there. In crops, they are mostly found in paddocks with large amounts of stubble or crop litter, and may affect all winter-sown crops.

There are a large and varied number of species of false wireworms, but all species exhibit some common 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. There are several common groups (genera) of false wireworms found in south-eastern Australia:

- the grey or small false wireworm (*Isopteron punctatissimus* or *Cestrinus punctatissimus*)
- the large or eastern false wireworms (*Pterohelaeus* spp.)
- the southern false wireworms (*Gonocephalum spp.*) [74]

In the grey or small false wireworm, the larvae grow to about 9 mm in length. They are grey-green, have two distinct protrusions from the last abdominal (tail) segment, and tend to have a shiny exterior (Figure 17). [75] Hence, they are most easily recognised in the soil on sunny days when their bodies are reflective. The adults are slender, dark brown and grow to about 8 mm in length. The eggs are less than 1 mm

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73 P Umina, B Kimber (2015) Lucerne seed web moth or Etiella. PestNotes, cesar Australia. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-seed-web-moth-or-Etiella

74 G McDonald (1995) Wireworms and false wireworms. Note AG0411. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms

75 G McDonald (2016) Grey false wireworm. Updated. cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Grey-false-wireworm

in diameter. There are several species of this pest genus, although *I. punctatissimus* appears to be the one most associated with damage.

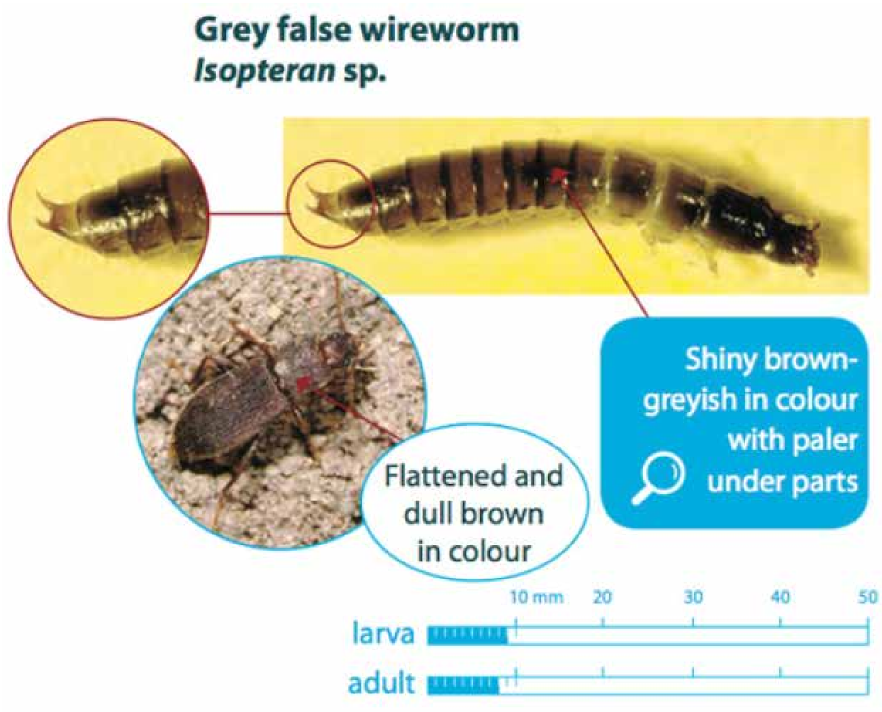


Figure 17: *Distinguishing characteristics of the grey false wireworm.*

Source: cesar

The large or eastern false wireworms are the largest group of false wireworms. They are the most conspicuous in the soil, and grow up to 50 mm in length. They are light cream to tan in colour, with tan or brown rings around each body segment, giving the appearance of bands around each segment. The last abdominal segment has no obvious protrusions, although, under a microscope, a number of distinct hairs can be seen. Adults are large, conspicuous and often almost ovoid beetles with a black shiny bodies (Photo 20). [76]

Photo 20: *Eastern false wireworm beetle (left) and larva (right).*

Source: cesar

The southern false wireworms grows to about 20 mm in length, and have similar body colours and marking to the large false wireworms. Adults are generally dark brown–

76 G McDonald (2016) Eastern false wireworm. Updated. cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Eastern-false-wireworm

grey, oval beetles, which sometimes have a coating of soil on the body (Figure 18). [77] The edges of adults' bodies are flanged, hence the common name pie-dish beetles.

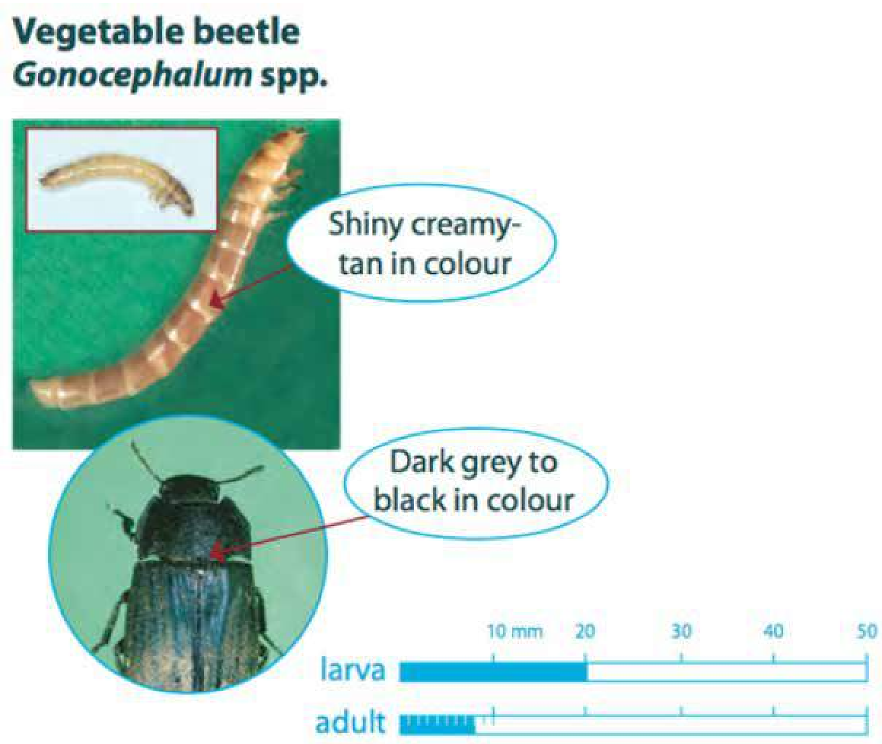


Figure 18: *Distinguishing characteristics of the southern false wireworm.*

Source: cesar

Biology

Usually only one generation occurs each year. However, some species may take up to 10 years to complete the life cycle. Adults emerge from the soil in December and January, and lay eggs in or just below the soil surface, mostly in stubbles and crop litter. Hence, larvae are most commonly found in paddocks where stubble has been retained.

Larvae of most false wireworm species prefer to feed on decaying stubble and soil organic matter. When the soil is reasonably moist, the larvae are likely to aggregate in the top 10–20 mm where the plant litter is amassed. However, when the soil dries, the larvae move down through the soil profile, remaining in or close to the subsoil moisture, and occasionally venturing back to the soil surface to feed. Feeding is often at night when the soil surface is dampened by dew.

Nothing is known about what triggers the false wireworm to change from feeding on organic matter and litter to feeding on plants. However, it is recognised that significant damage to plants is likely to occur when soils remain dry for extensive periods. Larvae are likely to stop feeding on organic matter when it dries out, and when crop plants provide the most accessible source of moisture.

Damage caused by false wireworms

Affected crops may develop bare patches, which could be large enough to require re-sowing (Photo 21). [78] Damage is usually greatest when crop growth is slow due to cold, wet conditions.

77 P Umina, G McDonald (2015) Southern false wireworm. cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Southern-False-wireworm

78 P Umina, G McDonald (2015) Southern false wireworm. cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Southern-False-wireworm

Photo 21: *False wireworm damage to pasture.*

Source: cesar

Infestations of the small false wireworm can be as high as hundreds of larvae per square meter, although densities as low as five larger false wireworm larvae per square meter can cause damage under dry conditions.

The larvae of the small false wireworm are mostly found damaging fine seedling crops shortly after germination. They feed on the hypocotyl (seedling stem) at or just below the soil surface. This causes the stem to be ring-barked, and eventually the seedling may be lopped off, or it wilts in warm conditions. Larger seedlings (e.g. those of grain legumes) may also be attacked, but the larvae appear to be too small to cause significant damage.

The larger false wireworms can cause damage to most field crops. The larvae can hollow out germinating seed, sever the underground parts of young plants, or attack the above-surface hypocotyl or cotyledons. In summer, adult beetles may also chew off young sunflower seedlings at ground level. Damage is most severe in crops sown into dry seedbeds and when germination is slowed by continued dry weather.

7.16.2 True wireworm

The true wireworms are many species in the family Elateridae. The slow-moving larvae in this family tend to be less common in broadacre cropping regions, although they are always present. They are generally associated with wetter soils than the larvae of false wireworms.

Larvae grow to 15–40 mm, are soft-bodied, and flattened, and these characteristics help distinguish them from false wireworms. Their colour ranges from creamy yellow in the most common species to red-brown; their head is dark brown and wedge-shaped. The tail piece is characteristically flattened and has serrated edges. Adults are known as click beetles, due to their habit of springing into the air with a loud click when placed on their backs. The beetles are dark brown, elongated and 9–13 mm long (Figure 19). [79]

79 B Kimber (2015) True wireworm. cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/True-wireworm

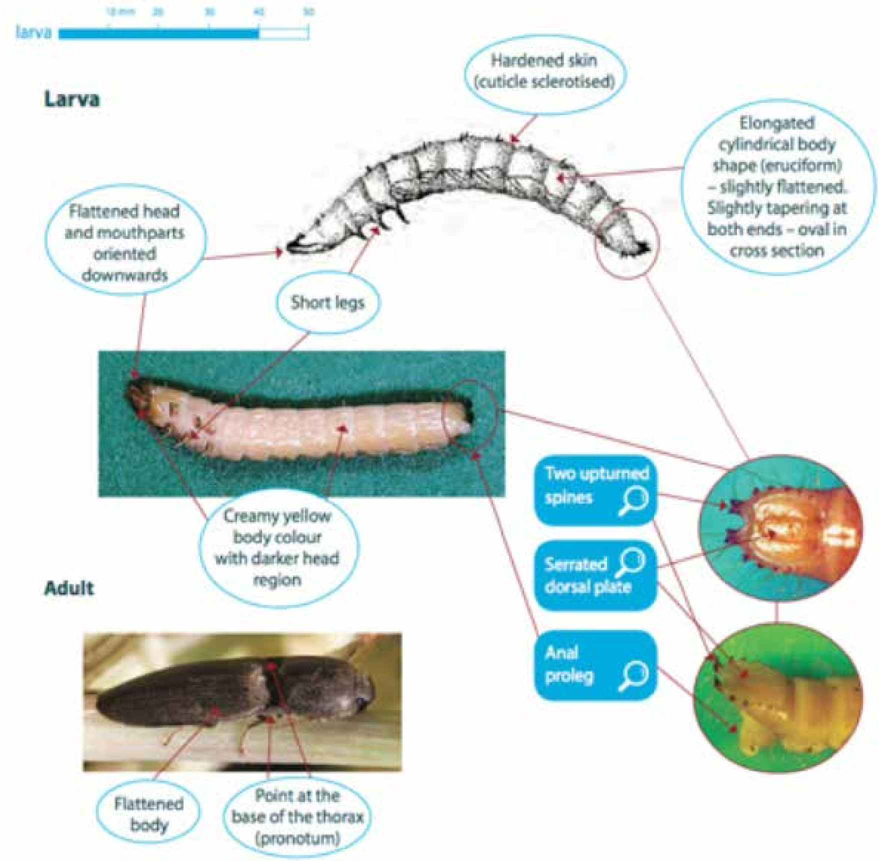


Figure 19: *Distinguishing characteristics of true wireworms.*

Source: cesar

Biology

There may be one or several generations per year, depending on the species. Wireworms prefer low-lying, poorly drained paddocks and are less common in dry soils. Larvae are reasonably mobile through the soil, and will attack successive seedlings as they emerge. Most damage occurs from April to August. Adults emerge in spring, and are typically found in summer and autumn in bark, under wood stacks or flying around lights.

There is little known of the biology of most species, although one species (*Hapatesus hirtus*) is better understood. It is known as the potato wireworm although it is found in many other crops and pastures, as well as in potatoes. It is very long-lived and probably takes five years or more to pass through all the growth stages before pupating and finally emerging as an adult beetle.

After emerging, adult click beetles mate and lay eggs, and then may spend a winter sheltering under the bark of trees. The connection between trees and adult beetles is probably why damage is often, but not always, most pronounced along tree lines. The wireworms have a long life in the soil and are active all year, even in winter.

Damage

The damage caused by wireworms is similar to that of false wireworms, except that most of it is restricted to below the soil surface. Larvae eat the contents of germinating seeds, and the underground stems of establishing plants, causing wilting and death.

7.16.3 Management

Monitoring

The principles for detection and control of false and true wireworms are generally similar, although different species may respond slightly differently according to soil conditions.

Sampling

Paddocks should be sampled immediately before sowing. There are two methods, although neither is 100% reliable. This is because larvae change their behaviour according to soil conditions, particularly soil moisture and temperature. The two methods are:

- Soil sampling—take a minimum of five random samples from the soil. Each sample should consist of the top 20 mm of a 0.50 m x 0.50 m area. Carefully inspect the soil for larvae. Calculate the average density per square metre by multiplying the average number of larvae found in the samples by 4. Control should be considered if the average exceeds 10 small false wireworms, or 10 of the larger false wireworms.
- Seed baits—these have been used successfully to sample true and false wireworms in Queensland and overseas. Preliminary work has shown that they can be used to show the species of larvae present, and to give an approximation of density. Take 200–300 g of a large seed (e.g. any grain legume) and soak for 24 hours. Select 5–10 sites in the paddock and place a handful of the soaked seed into a shallow, 50 mm hole, and cover with about 10 mm of soil. Mark each hole with a stake, and excavate each hole after about seven days. Inspect the seed and surrounding soil for false wireworm larvae. This technique is most likely to be successful when there is some moisture in the top 100 mm of soil.

Detection

Larvae of the small false wireworms are relatively difficult, although not impossible, to see in grey and black soils because of their small size and dark colour. However, they can be found in the top 20 mm of dry soil by carefully examining the soil in full sun. They are usually found in the interface between the wet and dry soil. Larvae of the other false wireworm species are more prominent because of their relatively pale colour and large size.

Cultural control

Crop residues and weedy summer fallows favour survival of larvae and over-summering beetles. Clean cultivation over summer will starve adults and larvae and expose them to hot, dry conditions, thus preventing population increases. Suitable crop rotations may also limit increases in population numbers.

Chemical control

Seedbeds must be sampled before sowing if control is to be successful. Insecticides may be applied to soil or seed at sowing. Most chemicals registered to control false wireworm are seed treatments, although these may not be consistently reliable. They probably work best when the seedling grows rapidly in relatively moist soils. Adults may also be controlled with insecticide incorporated into baits. If damage occurs after sowing, no treatment is available other than re-sowing bare patches with an insecticide treatment. [80]

For up to date information for chemical registrations, see the APVMA website.

MORE INFORMATION

False wire worms in seedling crops

80 G McDonald (1995) Wireworms and false wireworms. Note AG0411. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms

7.17 Slugs and snails

Slugs and snails can be a major pest in southern NSW (Table 16). [81] Damaging populations of slugs have also been reported in seedling crops in northern NSW and southern Queensland in recent years.

Increased slug and snail activity may be due to the increase in zero- and minimum-till and stubble-retention practices because the amount of organic matter in paddocks increases and gives young slugs and snails a bigger food source. Other risk factors include prolonged wet weather, trash blankets, weedy fallows and a previous history of slugs and snails. Slugs and snails are best controlled before the crop is planted.

Table 17: *Description of common slugs and snails.*

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Slugs				
 Grey field or reticulated slug (*Deroceras reticulatum*) Photo: M. Nash, SARDI	Light grey to fawn with dark brown mottling 35–50 mm long Produces a white mucus	Rasping of leaves. (Complete areas of crop may be missing.)	Autumn to spring when conditions are moist, especially when soil moisture is >25%	Resident pest Surface active, but seeks moist refuge in soil macropores
 Black-keeled slug (*Milax gagates*) Photo: M. Nash, SARDI	Black or brown with a ridge from its saddle all the way down its back to the tip of the tail 40–60 mm long.	Rasping of leaves. (Complete areas of crop may be missing.) Hollowed out grains	All year round if conditions are moist, but generally later in the season in colder regions	Burrows, so cereal or maize crops fail to emerge Prefers sandy soil in high rainfall areas (>550 mm), heavier soils in low rainfall areas (<500 mm). Surface active (feeding), but seeks moist refuge in soil macropores

81 IPM Guidelines (2016) Slugs and snails. Queensland Government and GRDC, http://ipmguidelinesforgrains.com.au/pests/slugs-and-snails/

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
 Brown field slug (*Deroceras invadens, D. laeve*) Photo: M. Nash, SARDI	Usually brown all over with no distinct markings 25–35 mm long Produces a clear mucus	Rasping of leaves Leaves a shredded appearance	All year round if conditions are moist	Prefers warmer conditions and pastures Less damaging than grey field slug and black-keeled slug
Snails				
 Vineyard or common white snail (*Cernuella virgate*) Photo: M. Nash, SARDI	Coiled white shell with or without a brown band around the spiral Mature shell diameter 12–20 mm Open, circular umbilicus* Under magnification, regular straight scratches or etchings can be seen across the shell	Shredded leaves where populations are high Found up in the crop prior to harvest	Active after autumn rainfall Breeding occurs once conditions are moist (usually late autumn to spring)	Mainly a contaminant of grain Congregates on summer weeds and off the ground on stubble
 White Italian snail (*Theba pisana*) Photo: M. Nash, SARDI	Mature snails have coiled white shells with broken brown bands running around the spiral Some individuals lack the banding and are white Mature shell diameter 12–20 mm Semi-circular or partly closed umbilicus* Under magnification cross-hatched scratches can be seen on the shell	Shredded leaves where populations are high Found up in the crop prior to harvest	Active after autumn rainfall Breeding occurs once conditions are moist (usually late autumn to spring)	Mainly a contaminant of grain Congregates on summer weeds and off the ground on stubble

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
 Conical or pointed snail (*Cochlicella acuta*) Photo: M. Nash, SARDI	Fawn, grey or brown Mature snails have a shell of up to 18 mm long The ratio of the shell length to its diameter at the base is always greater than two	Shredded leaves where populations are high Found up in the crop prior to harvest	Active after autumn rainfall Breeding occurs once conditions are moist (usually winter to spring)	Mainly a contaminant of grain Can be found over summer on and in stubble and at the base of summer weeds
 Small pointed snail (*Prietocella Barbara*) Photo: M. Nash, SARDI	Fawn, grey or brown Mature shell size of 8–10 mm long The ratio of its shell length to its diameter at the base is always two or less	Shredded leaves where populations are high Found up in the crop prior to harvest	Active after autumn rainfall Breeding occurs once conditions are moist (usually winter to spring)	A contaminant of grain, especially hard to screen from canola grain as the same size Mainly found over summer at the base of summer weeds and stubble Similar to slugs will go into soil macropores. Especially difficult to control with bait at current label rates

*Umbilicus: a depression on the bottom (dorsal) side of the shell, where the whorls have moved apart as the snail has grown. The shape and the diameter of the umbilicus is usually species-specific.

Source: IPM Guidelines

7.17.1 Damage caused by slugs and snails

Slugs will feed in the furrows on seeds of legumes. Snails are not known to damage seeds, but may damage germinated seeds close to the soil surface.

Irregular pieces chewed from leaves and shredded leaf edges are typical of snail and slug presence. Damage to legume crops can be difficult to detect if seedlings are chewed down to the ground during emergence.

Cereal crops are likely to survive damage by slugs and snails, while lupins cannot compensate for the damage or loss of cotyledons.

As the harvest season progresses snails migrate up the crop to escape the hot ground (Photo 22). This can become a problem at harvest time, especially if harvesting during high temperatures. If it is possible, harvest should be timed to coincide with cooler conditions.

Lupin crops need careful monitoring to assess plant losses. [82]

82 S Micic (2017) Identification and control of pest slugs and snails for broadacre crops in Western Australia. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C10

Photo 22: *White Italian snail in a lupin crop.*

Source: DAFWA

7.17.2 Economic thresholds for control

Thresholds (Table 18) can be unreliable due to the interaction between weather, crop growth and snail activity. For example, high populations in the spring do not always relate to the number of slugs and snails harvested. Their movement into the crop canopy is dictated by weather conditions prior to harvest. [83]

Table 18: *Thresholds for controlling snails and slugs in a paddock. If there are more than the number specified per metre for a given pest then actions for controlled the pest should be taken.*

Pest	Number of pest per square metre
Round snails	5
Small pointed snails	5 per seedling
Grey field slug	1–2
Black-keeled slug	1–2

Source: IPM Guidelines

7.17.3 Managing slugs and snails

Biological control

Free-living nematodes when carrying bacteria that kill snails and slugs are thought to help reduce populations under certain paddock conditions.

Note that baits containing methiocarb are toxic to a number of other invertebrates and beneficials.

83 IPM Guidelines (2016) Slugs in seedling crops. Queensland Government and GRDC, http://ipmguidelinesforgrains.com.au/pests/slugs-and-snails/slugs-in-seedling-crops/

Natural enemies of slugs

Some species of carabid beetles can reduce slug populations, but generally not below established economic thresholds. They can be important factor in controlling slugs, in combination with baiting. Many other soil fauna, such as are protozoa, may cause high levels of slug egg mortality under moist, warm conditions. Biological controls alone cannot be solely relied on for slug control.

Cultural control

Pre-season:

- Hard grazing of stubbles
- Cabling and/or rolling of stubbles when soil temperature is above 35°C
- Burning if numbers are very high and you can ensure hot, even burns
- Cultivation that leaves a fine, consolidated tilth
- Removal of summer weeds and volunteers

Reduce contamination by:

- Stripper fronts in medium to heavy crops
- Raising cutting heights
- Harvester modifications (see Snail fact sheet)
- Seed cleaning (see Snail fact sheet)

Windrowing:

- Trials with windrowed barley resulted in reduced round snail contamination
- Early windrowing when cool weather produces better results

Chemical control

Snails

Molluscidial baits containing either metaldehyde or chelated iron are IPM compatible. Apply to the bare soil surface when snails are active after autumn rain, as early as March. Aim to control snails pre-season.

Mature snails over 7 mm in length or diameter will feed on bait while bait is less effective on juveniles. Baiting before egg lay is vital. Try to bait when snails are moving from resting sites after summer rains. Stop baiting eight weeks before harvest to avoid bait contamination in grain. Bait rates need to be at the highest label rate to achieve a greater number of bait points. As the actual number is yet to be determined, label rates may be revised ion the future. In cool, moist conditions, snails can move 30 m/week, so treated fields can be re-invaded from fence lines, vegetation and roadsides. Rain at harvest can cause snails to crawl down from crops.

Slugs

Baiting is the only chemical option available to manage slugs. Molluscidial baits containing metaldehyde or chelated iron are IPM compatible. Baits containing methiocarb are also toxic to carabid beetles, one of the few predators of slugs. Different responses to bait can be due to species behaviour. The value of applying bait after a significant rainfall event prior to sowing is still to be tested.

For black-keeled slugs, broadcast baits when dry or place with seed at sowing.

For grey field slugs, broadcast baits.

Do not underestimate slug populations: always use rate that gives 25–30 baits points per metre.

Calibrate bait spreaders to ensure width of spread, evenness of distribution and correct rate. Make sure to bait after/at sowing prior to crop emergence when soil is moist (>20% soil moisture). Re-apply baits to problem areas 3–4 weeks after first application if monitoring indicates slugs are still active.

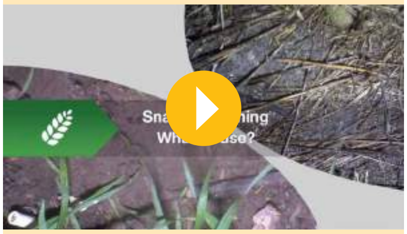
MORE INFORMATION

Identification and control of pest slugs and snails for broadacre crops - Pre-seeding management

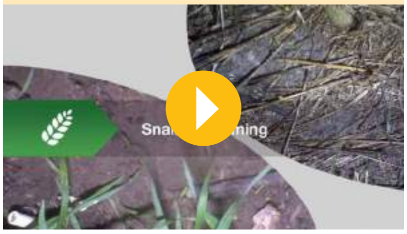
Bash ‘em, Burn ‘em, Bait ,em – Integrated snail management in crops and pastures.

VIDEOS

WATCH: Snail bait – what to use

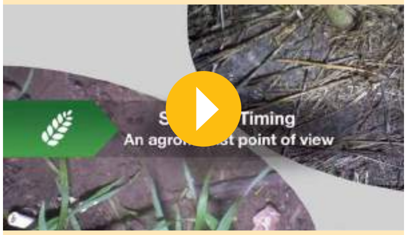


WATCH: Snail Bait timing

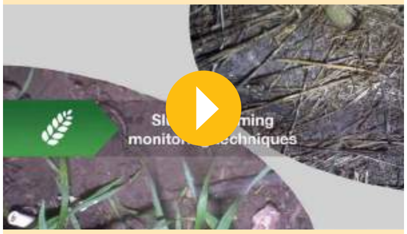


VIDEOS

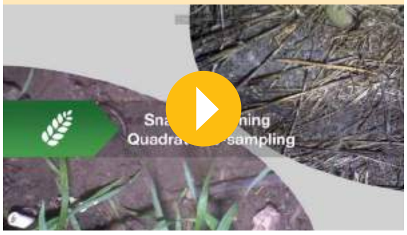
WATCH: Slug bait timing – an agronomists POV



WATCH: Slug bait timing – monitoring techniques



WATCH: Snails – quadrat sub-sampling



MORE INFORMATION

Identification and control of pest slugs and snails for broadacre crops - Chemical control

Note that the number of baits/ha is more important than total weight of bait per hectare. The minimum baits needed for effective control is 250,000 bait points per hectare.

For up to date information for chemical registrations, see the APVMA website.

Monitoring snails

Monitor regularly to establish numbers, types and activity (Table 19), and measure success of controls. Look for snails early morning or in the evening when conditions are cooler and snails are more active.

Key times to monitor:

- 3–4 weeks before harvest to assess need for harvester modifications and cleaning
- after summer rains, check if snails are moving from resting sites
- summer to pre-seeding, check numbers in stubble before and after rolling, slashing or cabling

Monitoring technique:

- sample 30 x 30 cm quadrat at 50 locations across the paddock.
- if two groups (round and conical) are present, record the number of each group separately
- to determine the age class of round snails, place into a 7 mm sieve box, shake gently to separate into two sizes >7 mm (adults) and <7 mm (juveniles).
- make sieve boxes from two stackable containers, e.g. sandwich boxes, remove the bottom from one and replace by a punch-hole screen with screen size of 7 mm round or hexagonal
- use 5 sampling transects in each paddock, one each at 90 degrees to each fence line and the fifth running across the centre of the paddock, and take five samples (counts), 10 metres apart along each transect

Record the size and number of the snails in each sample. Average the counts for each transect and multiply this figure by 10 to calculate the number of snails per square metre in that area of the paddock.

Table 19: *Monitoring snails at different stages of crop development.*

Pre-sowing	Seedling–vegetative stages	Grain fill and podding stage	Harvest
High risk: • weedy fields • alkaline calcareous soils • retained stubble • wet spring, summer, autumn • history of snails All species congregate at the base of summer weeds or in topsoil. Pointed snails can also be found at the base of or up in stubble as well as inside stubble stems. Appear to build up most rapidly in canola, field peas and beans, but can feed and multiply in all crops and pastures. Most active after rain and when conditions are cool and moist Dormant in late spring and summer	**Damage:** • consume cotyledons, which may resemble crop failure • shredded leaves where populations are high • chewed leaf margins • irregular holes Wide range of sizes indicates snails are breeding in the area. If most snails are the same size, snails are moving in from other areas. Round snails favour resting places off the ground on stubble, vegetation and fence posts Pointed snails are found on the ground in shady places	Can be found up in the crop prior to harvest. Check for snails under weeds or shake mature crops unto tarps.	**Predominantly a grain contaminant** At harvest, snails move up in the crop and may shelter between grains or under leaves. They can also be found in windrows. The small pointed snail is especially hard to screen from canola grain due to similar size. Buyers will reject grain if: • more than half a dead or one live snail is found in 0.5 L of wheat • more than half a dead or one live snail is found in 200 g pulse sample

Source IPM Guidelines

Monitoring slugs

Monitor with surface refuges to provide an estimate of active density (Table 19). Refuges include:

- terracotta paving tiles
- carpet squares or similar

Use a 300 mm by 300 mm refuge when soil moisture is favourable (more than 20%) as slugs require moisture to travel across the soil surface. Slugs are attracted to the refuges from approximately 1 m, so numbers found can be used as numbers per square metre.

Place refuges in areas of previous damage, after rainfall, on damp soil before sowing. Use 10 refuges per 10 hectares.

Check the refuges early in the morning, as slugs seek shelter in the soil as it gets warmer. Alternatively, put out metaldehyde bait strips and check the following morning for dead slugs. Monitor for plant damage.

Slug populations are not evenly distributed in the paddock and are often clumped. Where crop damage is evident inspect the area at night. [84]

84 IPM Guidelines (2016) Slugs in seedling crops. Queensland Government and GRDC, http://ipmguidelinesforgrains.com.au/pests/slugs-and-snails/slugs-in-seedling-crops/

MORE INFORMATION

GRDC factsheet, Slug identification and management

Table 20: *Monitoring slugs at different stages of crop development.*

Pre-sowing	Germination–vegetative stages
High risk: • high rainfall areas >450 mm a year • above-average spring–autumn rainfall • cold, wet establishment conditions • no-till stubble retained • summer volunteers • previous paddock history of slugs • soils high in clay and organic matter Slugs are nocturnal and shelter during dry conditions and generally not visible	**Damage:** • rasping of leaves, • leaves have a shredded appearance • complete areas of crop may be missing Slugs will eat all plant parts but the seedling stage is most vulnerable and this is when major economic losses can occur Grey and brown field slugs are mainly surface-active but the black-keeled slug burrows and can feed directly on germinating seed

Source IPM Guidelines

Nematode management

Key messages

- Nematodes are microscopic organism that can cause significantly yield losses to susceptible crops.
- Root-lesion nematodes (*P. thornei* and *P. neglectus*) have been detected at potentially damaging levels in nearly 30% of paddocks in the northern part of the Northern Region, and can be common throughout the southern part of the Northern region.
- Lupin is resistant to both *P. neglectus, P. thornei* and Cereal cycst nematodes (CCN), so can be used as a break crop in cereal rotations.
- There is no easy solution to RLN infestation. Variety and crop rotation are currently the major management tools

Soil testing (e.g. with PreDicta B) is the best way to diagnose nematode infestations and also to inform management decisions.

Nematodes or 'Eelworms' are found in all soils in high numbers and with high diversity. They are microscopic unsegmented roundworms that are one of the most numerous life forms on earth. While many species are free-living and play an important part in organic matter recycling, other species are parasitic to either plants or animals. Plant parasitic nematodes live in plant roots and other plant parts, causing disease. Parasitic nematodes have many hosts and are seldom plant-specific.

The aboveground symptoms of disease caused by nematodes can be difficult to detect, and may be often confused with symptoms of nutrient deficiency. Typically, plants do not thrive, are paler than normal, and may wilt in the heat of the day. Affected plants are often dwarfed, with small leaves. Sometimes, when infected plants are growing in moist, fertile soil, or during cool weather, the aboveground parts can still appear healthy. [1]

The two major groups of plant parasitic nematode in Australia's cropping regions are Root-lesion nematode and Cereal cyst nematode.

8.1 Root-lesion nematodes

The root-lesion nematodes are a genus of soil-borne, microscopic plant parasites that are migratory. They are widely distributed in the wheat-growing regions of Australia, the two common species in the Northern Region being *Pratylenchus thornei* (*Pt*) and *P. neglectus (Pn)*. *P. thornei* is the most damaging species and occurs commonly in the northern part of the Northern region (Photo 1). [2] *P. neglectus* occurs less frequently in this area, but is common and can be damaging in the southern part of the Northern region.

1 C. Wilkinson. (2014). Nematodes. DAFWA. https://www.agric.wa.gov.au/nematodes/nematodes

2 GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, http://www.grdc.com.au/TT-RootLesionNematodes

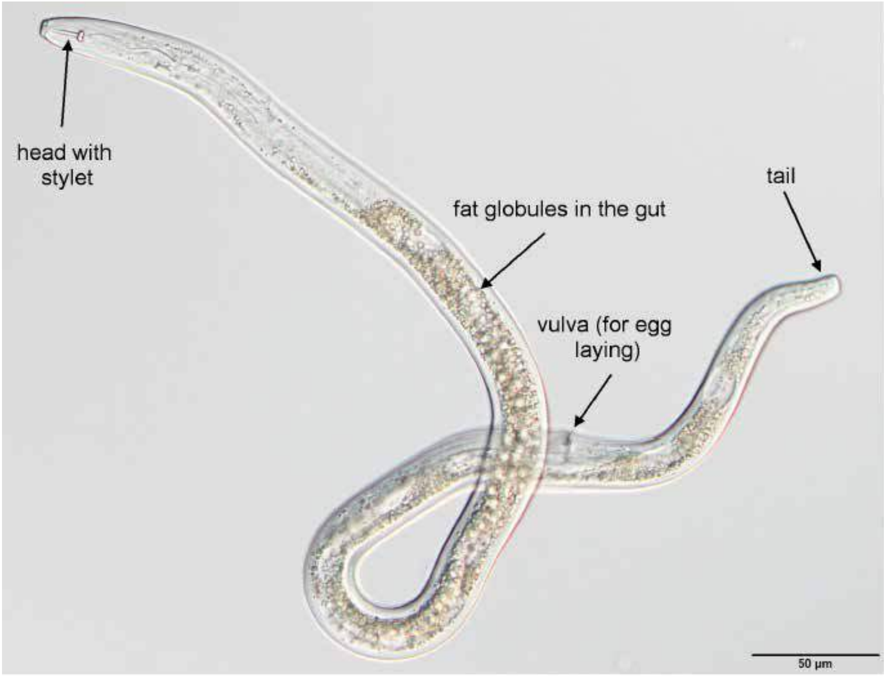


Photo 1: *A Pratylenchus thornei adult female viewed under the microscope. The nematode is approximately 0.65 mm long.*

Source: GRDC

Both species grow to ~0.5–0.75 mm in length and feed and reproduce inside the roots of susceptible crops (and other plants). They penetrate the plant root, digesting the cells' contents and laying eggs within the roots (Photo 2). [3] Nematode multiplication differs both between and within host species.

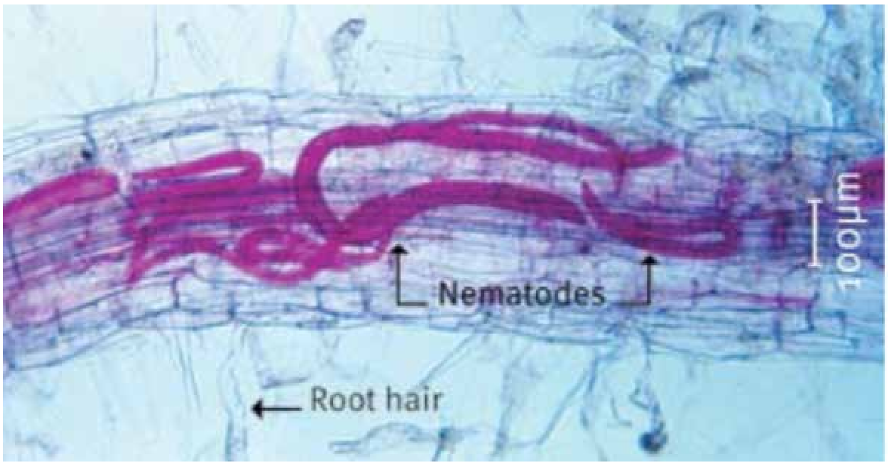


Photo 2: *Nematodes (stained to make them easy to see) in a cereal-plant root.*

Source: DAF Queensland

Pratylenchus thornei occurs throughout the root zone while *P. neglectus*, tends to be concentrated in the top 15 cm of the soil.

Big populations develop quickly following planting, so that the root systems quickly become inefficient in absorbing water and nutrients. [4]

P. neglectus has a wide range of hosts, and infects all cereals as well as crops grown in rotation with cereals (e.g. grain legumes, pasture legumes and oilseeds). This

3 J Thompson, K Owen, T Clewett, J Sheedy, R Reen (2009) Management of root-lesion nematodes in the northern grain region. DAF Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematode

4 GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, www.grdc.com.au/TT-RootLesionNematodes

species impairs root function, limiting water and nutrient uptake, and leading to poor growth and yield decline.

Compared to other crops, lupin is resistant to *P. neglectus* and *P. thornei*, the most damaging RLNs in the Northern region (Table 1).

Table 1: *Susceptibility of some non-cereal crop and pasture species to root lesion nematode infection.*

RLN species	Susceptible crops	Moderately susceptible crops	Resistant crops
Pratylenchus neglectus	Canola, chickpeas, mustard	Common vetch, lentils	Field peas, lupins, faba beans, triticale, safflower, cereal rye, medic, clover
Pratylenchus thornei	Chickpeas, vetch, faba beans	Canola, mustard, field peas*, lentils	Field peas*, lupins

* New field pea varieties are more susceptible to *P. thornei* than older varieties, so check the classification of each variety.

Source: GRDC

Root-lesion nematodes can complete several generations during growth in a susceptible crop. RLN develop from an egg and pass through four juvenile stages to become an egg-laying female. The females are self-fertile and males are rarely found of *P. thornei* and *P. neglectus*. Under ideal conditions, the life cycle takes about 6 weeks for *P. thornei*, depending on the temperature. Populations of RLN increase with each generation; therefore, more plant roots are damaged, which in turns restricts the uptake of water and nutrients from the soil (Figure 3).

VIDEOS

WATCH : GCTV6: Root-lesion nematodes

WATCH : Understanding root-lesion nematodes

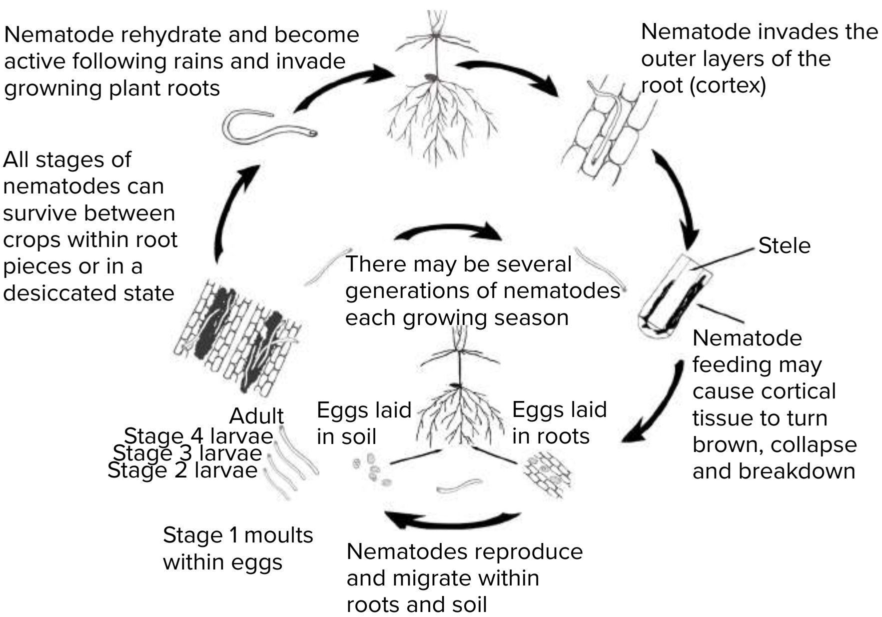


Figure 1: *Disease cycle of root-lesion nematode, adapted from: GN Agrios (1997) Plant Pathology, 5th edition (Academic Press: New York).*

Illustration by Kylie Fowler

In 2015, SARDI generated maps of the distribution of *P. thornei* and *P. neglectus* from samples submitted for PreDicta B tests (Figure 2). [5] Results from the autumn samples show that in the northern part of the Northern Region, *P. thornei* (Pt) is more widely distributed and found in greater, more damaging populations than *P. neglectus* (Pn). In this region, paddocks with more than 15 *P. thornei*/g soil or 15,000/kg soil (ascertained by the PreDicta B test) are considered high risk for crops. However, populations of *P. thornei* classified as being of medium risk, that is 2–15/g soil or 2,000–15,000/kg soil, can cause substantial yield loss in intolerant varieties in the warm, wet growing seasons that are conducive to nematode reproduction. [6]

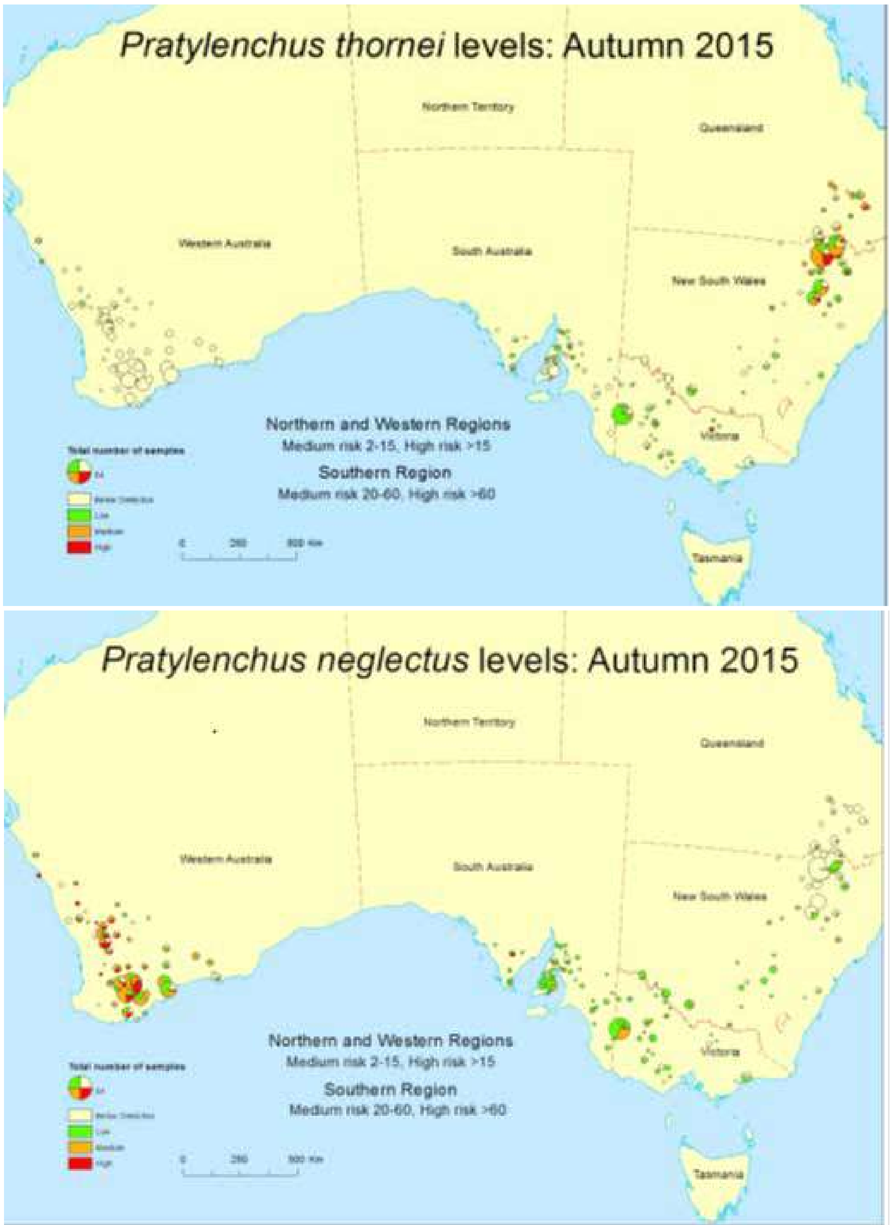


Figure 2: *The distribution of RLNs and risk of yield loss, from samples submitted for PreDicta B tests to SARDI in autumn 2015 for (top) Pratylenchus thornei and (bottom) P. neglectus.*

Source: GRDC

MORE INFORMATION

Managing grain crops in nematode infested fields

5 K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode fields to minimize loss and optimise profit. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit

6 K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode-infested fields to minimise loss and optimise profit. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit

In a survey of soil samples from 596 paddocks in southern Queensland and northern New South Wales cropping areas consistently show *P. thornei* presence in ~60–70% of paddocks. *This nematode is* frequently present at concerning levels, detected at over 2 *Pt*/g soil in ~30–40% of paddocks. In this survey, it was found that 42% of paddocks tested had *P. thornei* alone, 27% had both species, 6% had *P. neglectus* alone, and 26% had neither species (Figure 5). [7]

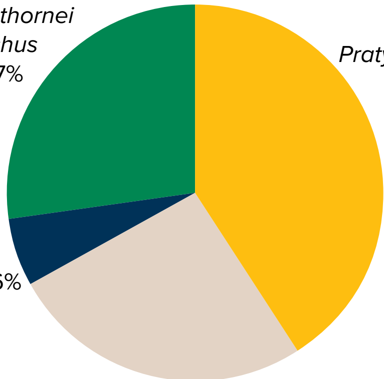


Figure 3: *A survey of nematodes in 596 paddocks in the Northern Region revealed that P. thornei is the most commonly found root-lesion nematode in the region (prior to recent region boundary changes) and that P. neglectus is also present.*

Source: DAF Queensland

8.1.1 Varietal resistance or tolerance

Research into lupin variety resistance and tolerance to RLNs is limited. Lupin crops are resistant to both *P. neglectus* and *P. thornei*. [8] Trials in Western Australia in 2015 found that Lupins were resistant to *P. quasitereoides*, but were highly susceptible to *P. penetrans*. [9] These RLNs are not common in the Northern region, however they can cause major damage to crops in the Western region.

What does resistance and tolerance mean?

Resistant varieties will result in fewer nematodes remaining in the soil to infect subsequent crops. Tolerant varieties are able to perform well in the presence of the nematode, but they may allow nematode populations to build up.

Nematode Resistance relates to the effect of the variety on the nematode density present within the paddock (Table 2).

7 J Thompson, K Owen, T Clewett, J Sheedy, R Reen (2009) Management of root-lesion nematodes in the northern grain region. DAF Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematode

8 A McKay (2012) Root-lesion nematode – South Australia. Soilquality.org. http://www.soilquality.org.au/factsheets/root-lesion-nematode-south-australia

9 M Williams (2016) Managing root lesion nematodes pre-sowing. GRDC. https://grdc.com.au/Media-Centre/Media-News/West/2016/03/Managing-root-lesion-nematodes-presowing

Table 2: *Standard disease ratings.*

Uniform rating	Management option description	In the paddock	Management action
Resistant	Growing these varieties will reduce the density of the nematode in question and so reduce yield loss in subsequent intolerant crops.	There will be a reduction in nematode densities when these varieties are grown.	Use these varieties in rotation with non-host crops to reduce nematode infestations. If using R varieties in paddocks with high nematode infestations make sure variety is also tolerant to prevent significant yield loss.
Moderately resistant	Growing these varieties will, to a lesser degree than growing a resistant variety, reduce the density of the nematode in question and, therefore, reduce yield loss in subsequent intolerant crops.	There will be a reduction in nematode densities when these varieties are grown.	These varieties are suitable to be grown in paddocks with high nematode infestations as they reduce nematode densities. They will, however, not reduce nematode densities to the same degree as a resistant variety. Note that if nematode densities are high tolerant to minimise yield loss.
Moderately susceptible	Growing these varieties will result in a small increase in nematode densities during the season.	Growing these varieties will increase the nematode density. However, unless the season is exceptionally favourable, growing these varieties in paddocks with low level nematode densities will only increase densities to moderate levels. If nematode densities are already moderate these varieties may result in high densities that may cause substantial loss in a following intolerant variety.	These varieties are suitable to be grown in paddocks with low nematode densities. They will, however, increase nematode densities which may be a problem for a following intolerant crop.

Uniform rating	Management option description	In the paddock	Management action
Susceptible	Growing these varieties will increase nematode density which may then cause problems to a following intolerant crop.	Growing these varieties will result in increases in the density of the nematode in question. However, unless the season is exceptionally favourable, growing these varieties in paddocks with a low level will only result in moderate levels. If nematode densities are already moderate these varieties can result in high levels that may cause substantial loss in a following intolerant variety.	These varieties will increase the density of nematodes in a paddock that may be of concern to a following intolerant crop. If nematode densities are high following a susceptible crop, growers should avoid intolerant crops in the following year and select a resistant crop to reduce nematode densities.
Very susceptible	Growing these varieties will support large multiplication rates of the nematode. It may take more than one year of a resistant variety/non-host crop to reduce the nematode densities to a level that will not affect the yield of an intolerant crop.	These varieties will support large increases in nematode numbers when grown in infested paddocks.	Growers should where possible avoid growing these varieties in infested paddocks. Also avoid growing intolerant varieties after VS varieties due to the potential for significant yield loss. A tolerant non-host crop/ resistant variety should be used following VS varieties to reduce nematode densities. If nematode densities are very high it may take more than two years of non-host/resistant varieties to reduce nematode levels to low risk densities.

Source: NVT Online

Nematode Tolerance relates to yield of the variety in the presence of the nematode (Table 3).

Table 3: *Standard disease ratings.*

Uniform rating	Management option description	In the paddock	Management action
Tolerant	Variety will not lose yield in the presence of the nematode, even at high nematode densities.	The crop will not be affected by the presence of the nematode.	No economic management decisions required.
Moderately tolerant	These varieties can generally be sown in paddocks with low to medium levels of nematode infestations without a significant effect on grain yield occurring. These varieties can suffer yield loss (up to 10%) in the presence of high nematode densities.	Minimal yield loss will occur in the presence of the nematode (i.e. < 5%), except when nematode densities are high when up to 10% yield loss may occur.	Do not grow these varieties in paddocks with high nematode densities present. Suggest follow management recommendations to minimise yield loss for the nematode of concern.
Moderately intolerant	These varieties should not be grown in paddocks with medium to high nematode densities. In the presence of high nematode densities in a paddock these varieties will lose up to 30% yield.	In the presence of the nematode and in seasons conducive to disease, these varieties will lose yield and may show symptoms consistent with root damage. The expression of symptoms will be greater in paddocks with higher nematode densities.	These varieties should not be grown in paddocks with medium to high nematode densities. In the presence of high nematode densities in a paddock these varieties can lose up to 30% yield. Suggest follow management recommendations to minimise yield loss for the nematode of concern.
Intolerant	These varieties are prone to yield loss even in the presence of low nematode densities. Such varieties should not be grown in paddocks where nematodes are known to be present. In the presence of high nematode densities yield loss of up to 50% can occur.	In the presence of the nematode symptoms of root disease will often be easily found in the crop.	Do not grow these varieties in paddocks where the nematode is present at medium to high levels. Even paddocks with low nematode densities should be avoided when possible. Suggest follow management recommendations to minimise yield loss for the nematode of concern.

VIDEOS

WATCH: GCTV19: Root-lesion nematodes—Resistant cereal varieties have surprising impacts on RLN numbers

Uniform rating	Management option description	In the paddock	Management action
Very intolerant	Do not grow this variety unless the paddock is known to be nematode free or present at very low densities. High nematode densities could cause yield losses of greater than 50% to occur.	Symptoms of nematode damage will be present in these varieties even in the presence of low nematode densities.	Do not grow these varieties in paddocks where the nematode is present, even at low levels. If the variety is to be grown a soil test should be conducted prior to sowing to ensure that the paddock is free from the nematode in question. Suggest follow management recommendations to minimise yield loss for the nematode of concern.

Source: NVT Online

8.1.2 Symptoms and detection

Because lupin are resistant to the RLNs in the Northern region, symptoms are unlikely to occur. Growers may notice symptoms in other crops in the sequence, however, even these sypmtoms can be difficult to identify and attribute to nematode damage.

Damage from RLN results in brown root lesions but these can be difficult to see or can also be impacted by other organisms. Root systems are often compromised with reduced branching, reduced quantities of root hairs and an inability to penetrate deeply into the soil profile. RLN create an inefficient root system that reduces the ability of the plant to access nutrition and also soil water.

An examination of washed plant roots may provide some information, but symptoms can be difficult to see and roots are difficult to remove from heavy clay soils.

Visual damage above ground from RLN is non-specific. Lower leaf yellowing is often observed together with reduced tillering and a reduction in the amount of crop biomass. Symptoms are more likely to be observed later in the season, particularly when the crop is reliant on sub soil stored moisture.

In the early stages of RLN infection, localised patches of poor performing crops may be observed. Soil testing of these patches is one of the only ways to determine or eliminate RLN as a possible issue.

Soil testing

Soil testing is the best way to diagnose nematode infestations and also to inform growers' management decisions. It is essential to know whether nematodes are on your farm and which species are present. This is important because varietal tolerance information for *P. thornei* does not hold true for *P. neglectus*, so proper species identification can help minimise losses that arise from planting intolerant varieties in nematode-infested land.

RLN populations can persist in the soil for a long time, so it is important to know the size of the population at the end of each season. Once a population increases, non-host, resistant crops or fallows are required to reduce the population below the damage threshold. Planting susceptible or tolerant crops within this period will enable the rapid increase in populations to higher levels. [10]

There are two services available to test for RLNs.

10 J Whish, J Thompson (2016) How long does it take to reduce Pratylenchus thornei (root lesion nematode) population in the soil? GRDC Update Paper. GRDC, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil

Leslie Research Centre tests

The Leslie Research Centre of the Department of Agriculture and Fisheries Queensland offers a commercial test for the presence of nematodes in soil.

Since nematodes may not be evenly spread across a paddock, particularly when there are new infestations, it is important to take samples from several locations within a paddock. It is suggested that growers take nine cores in groups of three.

Nematodes are often more numerous in the subsoil than in the topsoil. Although you can have soil to a depth of 120 cm analysed, this isn't necessary. As long as soil is sampled in two layers, topsoil at 0–15 cm and subsoil at 15–30 cm, a useful result can be achieved. Use a hand corer (or a mattock if no corer is available). Topsoil-only samples can give inaccurate results and should always be accompanied by a subsoil sample. If deeper samples are already being taken for other analysis (e.g. nitrate), a nematode assessment can be made from the depths 0–30 cm, 30–60 cm and 60–90 cm.

Send samples to:
Soil Microbiology Section
Leslie Research Centre
PO Box 2282
Toowoomba, QLD 4350
13 Holberton Street
Toowoomba

Phone: (07) 4639 8888
Fax: (07) 4639 8800

MORE INFORMATION

Leslie Research Centre, Test your farm for nematodes

PreDicta B tests

PreDicta B is a DNA-based soil-testing service that was developed by the South Australian Research and Development Institute (SARDI) (The B in the name stands for broadacre). The test identifies which soil-borne pathogens pose a significant risk to broadacre crops before paddocks are planted (Figure 4). [11]

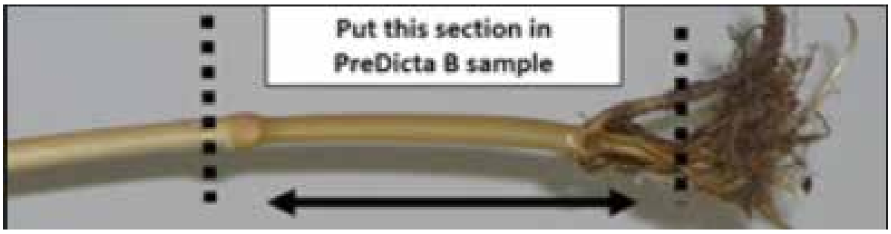


Figure 4: *It is important to follow the PreDicta B sampling instructions closely.*

Source: GRDC

PreDicta B can be used to test for:

- Root-lesion nematodes including *P. neglectus* and *P. thornei*
- take-all (*Gaeumannomyces graminis var. tritici (Ggt)* and *G. graminis var. avenae (Gga)*).
- Rhizoctonia root rot (*Rhizoctonia solani AG8*).
- crown rot (*Fusarium pseudograminearum and F. culmorum*).
- blackspot of peas (*Mycosphaerella pinodes, P. medicaginis var. pinodella* and *P. koolunga*).

11 D Lush (2014) PreDicta B sampling strategy. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2014/04/PreDicta-B-sampling-strategy

Testing service

Access PreDicta B diagnostic testing services through a SARDI accredited agronomist, who will interpret results and give advice on management options to reduce the risk of yield loss. Samples are processed weekly between February and mid-May (prior to crops being sown). PreDicta B is not intended for in-crop diagnosis.

8.1.3 Damage caused by RLNs

Root-lesion nematode numbers build up rapidly when susceptible crops are planted, and the build-up causes decreasing yields over several years. The amount of damage caused will depend on; the numbers of nematodes in the soil at sowing, the tolerance of the variety of crop being grown, and environmental conditions.

Lupin is unlikely to see this amount of damage as it is thought to be more resistant to RLN.

RLN infection of intolerant varieties restricts water and nutrient uptake early in the season, which limits aboveground plant development and yield potential. The impact of reduced root function is particularly noticeable around September–October in the Northern grain region as the crop draws on subsoil moisture and nematode populations increase with the rising soil temperatures. [12]

Field trials in areas infested with *P. neglectus* have shown yield losses for intolerant cereal varieties ranged from 12-33%. [13] In the southern part of the northern region *P. neglectus* can cause major losses to susceptible crops. In southern Australia *P. neglectus* has been known to reduce grain yield by 10-20% and in Western Australia is has been reported to cause losses of up to 15%. [14]

In the northern part of the Northern region, intolerant varieties can lose more than 50% in yield when *P. thornei* populations are high (Figure 5). [15]

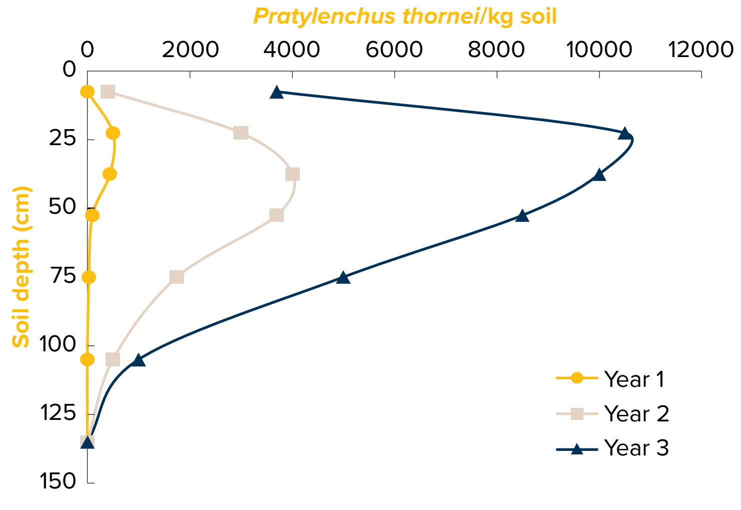


Figure 5: *During three years of continuous wheat cropping at Wellcamp (Queensland), numbers of Pt increased from low levels to levels that would reduce yields of intolerant crops. The graph shows numbers in the soil sampled before sowing each year.*

Source: DAF Queensland

12 GRDC (2015). Tips and tactics: Root-lesion nematodes – Northern Region. www.grdc.com.au/TT-RootLesionNematodes

13 B Burton, R Norton, R Daniel (2015) Root-lesion nematode; importance, impact and management. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

14 V Vanstone, J Lewis (2009) Plant parasitic nematodes Factsheet. GRDC.

15 B Burton, R Norton, R Daniel (2015) Root-lesion nematode: importance, impact and management. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

8.1.4 Conditions favouring development

Intensive cropping of susceptible crops will lead to an increase in RLN levels in the soil. Root lesion nematodes survive summer as dormant individuals in dry soil and roots, and become active after rain. They can survive several wetting/drying cycles. About three generations of the nematodes are produced each season, with the highest multiplication in spring.

Nematodes can spread through a district in surface water (e.g. floodwater) and can be moved from one area to another in soil that adheres to vehicles and machinery. They can also move via soil adhering to vehicles and farm machinery. In uninfested areas, good hygiene should be adopted. Nematodes can be spread in dust when they are in a dehydrated state over summer.

They have the ability to quickly build up populations in the roots of susceptible crops, and remain in the soil during fallow. As a result, the yield of following crops can be significantly reduced.

IN FOCUS

How long does it take to reduce Pt in soils?

Key points:

- Paddocks that host *P. thornei* populations greater than 40,000 per kg of soil at harvest will require a double break of around 40 months free of a host plant in order to reduce the population.
- Paddocks that host *P. thornei* populations greater than 10,000 per kg at harvest will require a single break of around 30 months free of a host plant in order to reduce the population below the accepted threshold.
- Weeds can be hosts, so fallows must be free of weeds and volunteers.

Researchers explored how long it takes to reduce Pt populations in infected soils. Using wheat cultivars with different levels of tolerance and resistance, they created a range of nematode populations in the soil. At the harvest of the second wheat crop, the nematode population in each plot was recorded and defined as high (H, >20,000Pt/cm^2/1.2 m soil profile), medium (M, >10,000Pt/cm^2/1.2 m profile), low (L, >5,000Pt/cm^2/1.2 m profile) or very low (VL, <5,000Pt/cm^2/1.2 m profile), and calculated as the sum of nematodes across the whole profile. Over the next 30 months soil samples were collected from the plots to monitor the change in nematode populations over time.

The rotation over the 30 months was wheat, followed by a long fallow to sorghum, then a long fallow to wheat. In the fallow that commenced in 2011, no sorghum was sown due to drought.

A paddock with a high initial number of nematodes (80 nematodes per cm^3, ~80,000 Pt/kg) took four years to reduce below the threshold. This required two non-host crops such as sorghum and fallows to reduce the population. A paddock with an initially medium level of nematodes (50 nematodes per cm^3) took 3.5 years to drop below the threshold (Figure 6), [16] and required the equivalent of a single non-host summer crop and fallows. A low nematode population paddock (20 nematodes per cm^3) took 24 months to drop below the threshold. [17]

16 J Whish, J Thompson (2016) How long does it take to reduce Pratylenchus thornei (root lesion nematode) population in the soil? GRDC Update Paper. GRDC, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil

17 J Whish, J Thompson (2016) How long does it take to reduce Pratylenchus thornei (root lesion nematode) population in the soil? GRDC Update Paper. GRDC, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil

MORE INFORMATION

[How long does it take to reduce Pratylenchus thornei (root lesion nematode) population in the soil?]

[Impact from *Pratylenchus thornei*, Macalister 2015]

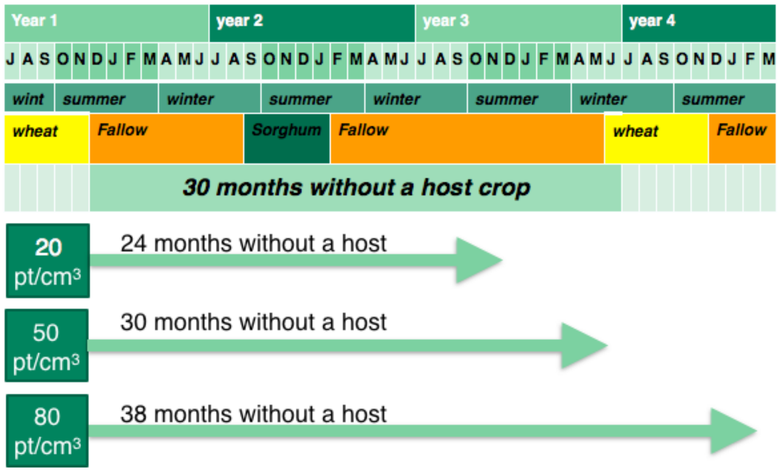


Figure 6: *An example of a non-host fallow showing the time required to reduce different starting populations of root-lesion nematode.*

Source: GRDC

8.1.5 Thresholds for control

The damage threshold for both RLNs has been estimated at 2,000 nematodes/kg soil (or 2/g soil). Control is warranted for paddocks with populations over this density. [18]

In the Northern region, paddocks with more than 15 *P. thornei*/g soil or 15,000/kg soil are considered high risk for crops. However, populations of *P. thornei* classified as being of medium risk, that is 2–15/g soil or 2,000–15,000/kg soil, can cause substantial yield loss in intolerant varieties in the warm, wet growing seasons that are conducive to nematode reproduction. [19]

The number of nematodes in the soil can be determined by conducting soil testing, for example with a PreDicta B test.

Note that this threshold is recommended for susceptible varieties and control is warranted when susceptible varieties are planned in a cropping sequence. [20]

8.1.6 Management

Key points:

- Test soil to monitor population changes in rotations and to determine RLN species and population density.
- Avoid consecutive susceptible crops in rotations to limit the build-up of RLN populations.
- RLN can multiply in cereal and legume crops and each nematode species can build up on different crops.
- Choose varieties with tolerance to maximise yields when RLN are present. Lupin is considered a break-crop for RLN.
- Choose rotation crops with high resistance ratings, so that fewer nematodes remain in the soil to infect subsequent crops.

18 GRDC (2015) Root lesion nematodes. Tips and Tactics. GRDC, www.grdc.com.au/TT-RootLesionNematodes

19 K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode-infested fields to minimise loss and optimise profit. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit

20 GRDC (2015). Tips and tactics: Root-lesion nematodes – Northern Region. www.grdc.com.au/TT-RootLesionNematodes

- Two or more consecutive resistant crops may be needed to reduce damaging populations.

There are four key strategies in reducing the risk of root-lesion nematodes:

1. Have soil tested for nematodes in a laboratory (For more information, see Section 8.1.7 Soil testing).
2. Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.

Choose tolerant varieties to maximise yields; National Variety Trials online is a useful resource. Tolerant varieties grow and yield well when RLN are present.

1. Rotate with resistant crops to prevent increases in root-lesion nematodes (Figure 7 [21]). When high populations of RLN are detected you may need to grow at least two resistant crops consecutively to decrease populations. In addition, ensure that fertiliser is applied at the recommended rate to ensure that the yield potential of tolerant varieties is achieved. Crop rotation with resistant crops such as grain sorghum, millet, sunflower and lupins will reduce the numbers of nematodes in the soil to a level where susceptible varieties can be grown. However, it will not eliminate them completely. [22]

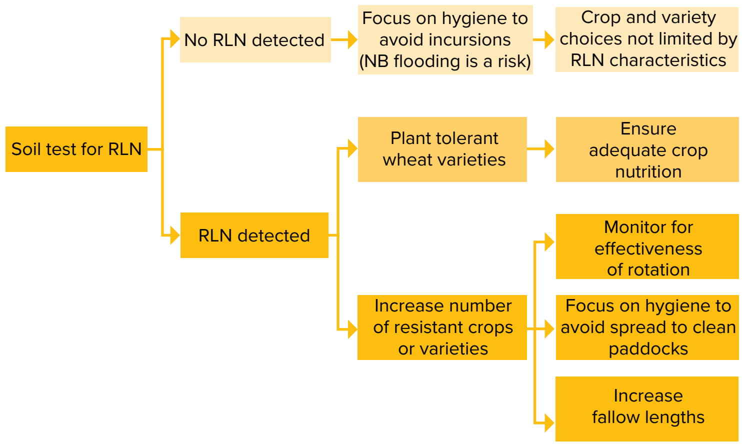


Figure 7: *The simplified RLN management flow chart. It highlights the critical first step in the management of RLN is to test soil to determine whether you have a problem to manage. Where RLN are present, growers should focus on both planting tolerant wheat varieties and increasing the number of resistant crops and varieties in the rotation.*

Source: GRDC

The first step in management of RLN is to have soil tested to determine whether RLN are present in paddocks. If RLN are detected, the soil test will tell you which of the species is present and the population level in the field. If RLN are not detected, protect those paddocks from contamination by controlling movement of soil and water on the farm. Clean soil from machinery before planting or fertilising, and plant RLN-free paddocks first.

When RLN are detected, rotations and variety choice are central to successfully reducing RLN populations. Only non-host crops or resistant varieties will minimise

21 B Burton, R Norton, R Daniel (2015) Root lesion nematodes: importance, impact and management. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

22 DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

the build-up of RLN (Table 4). Lupins are said to be one of the best crops in limiting *P. neglectus* populations. [23]

Aim to reduce populations to less than 2/g soil. Re-testing of soil after growing resistant crops is recommended, so that crop sequences can be adjusted if populations are still at damaging levels. Avoid very susceptible crops and varieties. [24] Consider re-testing in five years, particularly if there has been flooding, because RLN can move in floodwaters and in soil.

Table 4: *Comparison of the hosting ability of a range of cereal, pulse and weeds to root-lesion nematodes Pratylenchus thornei and P. neglectus. Lupins are at low risk of increasing populations of both RLNs in the Northern region.*

Crop	*P. thornei*	*P. neglectus*
Cereals		
Barley	Medium to high	Low to medium
Canary seed	Low	Low
Maize	Low	Low
Millet	Low	Low
Oats	Low	NT
Sorghum (grain)	Low	Medium to high
Triticale	Medium to high	Low
Wheat	Low, medium to high	Low, medium to high
Legumes		
Blackgram	High	Medium (p)
Chickpeas	Medium to high	Low to medium
Cowpeas	High	NT
Faba beans	Medium to high	Low
Field peas	Low to medium	NT
Navy beans	High	NT
Pigeon peas	Low	NT
Oilseeds		
Canola, mustard	Low to medium	Medium to high
Cotton	Low	Low
Linseed	Low	Low
Soybeans	High	Low
Sunflowers	Low	Low
Pastures, forage		
Brassica (forage)	Low to medium (p)	NT
Lablab	Low	NT
Sorghum (forage)	Low	Medium to high

Source: GRDC

23 V Vanstone (2010) in GRDC: Rotate crops to guard against root lesion nematodes. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-86-May-June-2010/Rotate-crops-to-guard-against-root-lesion-nematodes

24 GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, http://www.grdc.com.au/TT-RootLesionNematodes

VIDEOS

WATCH : Root lesion nematodes part 3: What can I do?

WATCH : Crop variety effect on nematodes

MORE INFORMATION

National Variety Trials

GRDC Tips and Tactics, Root-lesion nematodes, Northern Region

Fallow

RLN populations will generally decrease during a 'clean' fallow but the process is slow and expensive in lost potential income. Additionally, long fallows may decrease arbuscular mycorrhizae (AM) levels and create more cropping problems than they solve.

Weed control

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 oat, barley grass, brome grass and wild radish are susceptible to *P. neglectus*. When a pasture is included in the cropping rotation, weeds strongly influence nematode populations at the end of the pasture phase. Manage volunteer susceptible crop plants that can harbour nematodes. [25]

Nutrition

Ensure that adequate fertiliser is applied (especially nitrogen, phosphorus and zinc) so that tolerant varieties can reach their yield potential; high fertiliser rates do not lead to lower nematode reproduction. Although under-fertilising is likely to exacerbate the impact of RLN-affected yields, over-fertilising is unlikely to *compensate* for a poor variety choice.

Adequate nutrition normally allows plants to better tolerate plant parasitic nematodes, although this does not necessarily lead to lower nematode reproduction.

Field trials in areas infested with *P. neglectus* have shown yield losses for intolerant cereal ranged from 12-33% when minimal levels of phosphorus were applied but losses were reduced to only 5% with a high (50 kg/ha) rate of phosphorus.

Nematicides (control in a drum)

There are no nematicides or seed dressings registered for use against RLN in broadacre cropping in Australia. Screening of potential candidates continues to be conducted, but RLN are very difficult to target because populations are frequently deep in the soil profile. [26] Experiments with nematicides have shown that they provide poor control of RLN populations deep in the soil profile.

Natural enemies

Biological suppression is a potential method of reducing populations of *P. thornei* and *P. neglectus*. Recent research has identified that Northern Region soils are capable of suppressing root-lesion nematodes, especially in the top layer (0–15 cm), and this capacity can be enhanced by increasing the biological activity of that soil, mainly through carbon inputs and minimising soil disturbance.

Several organisms that prey on nematodes have been found in northern soils that have the potential to reduce root-lesion nematode populations. They include the *Pasteuria* bacteria that infect and eventually kill *Pratylenchus* spp. Several species of fungi, including some that trap nematodes, and predatory nematodes have also been found.

Research is continuing to develop methods of increasing biological activity to enhance natural suppression of nematodes deeper in the soil profile.

25 V Vanstone, J Lewis (2009) Plant parasitic nematodes Factsheet. GRDC.

26 B Burton, R Norton, R Daniel (2015) Root-lesion nematode; importance, impact and management. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

IN FOCUS

Biological suppression of RLN in northern soils

Key points:

- In one study, biological suppression occurred in most soils tested in the Northern grain-growing region, showing that populations of *RLN* are reduced by parasites and predators.
- Suppression was found to be greater in the top 10 cm of soil than at deeper layers (e.g. 30–45 cm). Practices such as zero tillage with stubble retention enhanced suppression. In the absence of these, it is estimated that RLN multiplication would be significantly greater, especially in topsoils, and that this would result in much greater losses in the productivity of susceptible crops.
- Several antagonists of *Pratylenchus* spp. were found in Northern grain-growing soils that enhance the plant's resistance to nematodes: nematode-trapping fungi, predatory nematodes, parasitic bacteria, and root-colonising fungi. Further research is focussing on these organisms as they are likely to contribute to the ability of natural subsoil systems to suppress RLN.

Actively enhancing the ability of soils to suppress root-lesion nematodes is a control option that deserves some consideration. In regard to RLN, disease suppression can be defined as the ability of a soil and its organisms to suppress the incidence or severity of disease even in the presence of the pathogen, host plants and favourable environmental conditions. The vast array of organisms in the soil can provide a degree of biological buffering against pathogens. Disease reduction results from the combined effects of many antagonists acting collectively and mediated through inputs of organic matter (general suppression) and direct antagonism by a limited number of organisms (specific suppression).

A recent GRDC-funded project aimed to better understand the suppressive nature of grain-growing soil environments and provide growers with methods to enhance the soils' ability to suppress root-lesion nematodes.

Over four years, researchers sampled 24 sites to test the suppressive nature of the soils. The sites were located in several farmers' paddocks and three long-term farm-management trial sites. The soils were given several fertiliser or tillage treatments. Also, seven of the sites were comparisons of cropped/pasture or native/scrub remnant soils that were close by to gain an understanding of the impact cropping may have on any natural ability of soils to suppress RLNs.

Repeated studies over four years of multiple soils from northern NSW and southern Queensland consistently showed that some soil environments have a natural ability to suppress root-lesion nematodes. In glasshouse tests, the researchers also found that a 10% addition of suppressive field soil to a sterilised soil (heated at 60°C for 45 mins) is sufficient to reduce RLN multiplication by 60–90%, showing that the suppressive effect was biological and could be transferred or added to a less suppressive soil.

Implications:

- Suppression does occur in most of the soils tested, as populations of *P. thornei* were reduced due to biological activity. Suppression was greater in the top 10 cm of soil than at deeper layers, and practices such as zero tillage with stubble retention enhanced the effect.
- Maintenance of a healthy topsoil through diverse organic matter inputs will preserve the potential of soils to naturally suppress RLNs.

MORE INFORMATION

[Biological suppression of RLN in northern region]

- Heavy rates of stubble (up to 20 t/ha) increased general suppression of RLN in the short term. This coincided with high levels of microbial activity.
- The presence of a crop for longer periods of time and the associated input of root exudates may have provided a better environment for sustained microbial activity and, hence, suppression of RLN.
- Growers using no-till, stubble-retention practices and cropping when soil moisture allows are probably doing a great deal toward enhancing the suppressive ability of their topsoils. Without these practices, RLN multiplication would probably be significantly greater, especially in topsoils, and therefore lead to much greater losses in productivity of susceptible crops.

More work is required to confirm the biological-control agents found to be present in grain-growing soils can have a significant impact on RLN populations on a broad scale. [27]

8.2 Cereal cyst nematodes

Lupin is resistant to Cereal cyst nematodes and can be used as a break crop to lower populations in the soil.

Only one race of CCN, *Heterodera avenae*, occurs in Australia and it can cause damage to cereal crops in southern NSW, Western Australia, South Australia, and Victoria. It only affects cereal varieties and can cause yield loss of up to 80% in intolerant varieties (Photo 3).

Photo 3: *Poor emergence and establishment in a cereal crop infected with CCN. This is will lead to yield losses.*

Source: DAFWA.

27 N Seymour, G Stirling, J Li (2016) Biological suppression of RLN in northern grain growing soils. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Biological-suppression-of-root-lesion-nematodes-in-northern-grain-growing-soils

If susceptible cereal varieties are continually used in a rotation CCN can cause ongoing significant yield losses.

If CCN is present at moderate to high levels growers need to implement rotations using tolerant and resistant cereals and non-host crops for at least two years and then monitor nematode levels before considering the use of susceptible varieties.

CCN infested paddocks in southern Australia are now relatively rare following the widespread adoption of rotations using resistant cereals and non-host crops.

Lupin is resistant to CCN and there are many wheat, barley, oat and triticale varieties now available that are also resistant to CCN (Table 5).

Table 5: *CCN ratings for crop types.*

Crop	Lupin	Wheat	Oat	Barley	Triticale
CCN rating	R	S-R	VS-R I-MT	S-R	R

Source: Agriculture Victoria.

See the Agriculture Victoria Cereal disease guide – 2017 for varietal resistant ratings to CCN.

8.2.1 Thresholds for control

Less than five eggs per gram of soil can produce yield loss for intolerant cereals, and can warrant CCN management in affected paddocks. Egg numbers can be detected using a PreDicta BTM soil test.

8.2.2 Management

CCN is easy to manage which is evidenced by the widespread reduction in paddock CCN levels that has taken place since the introduction of resistant varieties and extension of management strategies. CCN is much easier to manage than RLN because of the greater range of resistant and non-host crops available.

CCN only feeds on cereals and other grasses. The use of CCN-resistant cereals and non-host crops such as pulses and oilseeds (including lupins) in rotation is the main management strategy. Where CCN levels are moderate to high the best choice is two years of resistant and tolerant cereal or non-host crops. The most profitable option will often be chosen, but growers should also be mindful of management of other diseases and weeds when making these choices to produce longer-term profits. While two years is generally accepted to reduce CCN to low levels, exceptions do occur.

Break crops must be maintained free of wild oats and susceptible cereal volunteers. The benefit of a two-year break should be regarded as temporary because the nematode population rises quickly when susceptible cereals are returned to the system. The solution is not instant and it can take several years to reduce high levels.

Soil testing can help ascertain the risk. Monitoring paddocks and the use of diagnostic services to check CCN levels is encouraged. If cases of CCN infestation are suspected, growers are advised to check the roots of the host crops. Carefully digging up, then simply washing the soil from the roots of an infected plant can sometimes reveal evidence of infestation in the roots which warrants laboratory analysis. Testing services (e.g. PreDicta B) are available around Australia and growers are advised to contact their local agricultural department for advice. [28]

MORE INFORMATION

Plant parasitic nematodes factsheet

28 GRDC (2009) Plant parasitic nematodes – Factsheet.

8.3 Nematodes and crown rot

In the Northern Region, it is becoming more important to build a picture of the interaction of crown rot with other factors, especially in combination with *Pt* levels. As well as reducing yield, *Pt* reduces grain quality and N-use efficiency, and increases the severity of crown rot infections. [29] Lupin is a good break crop for RLNs and crown rot.

The Northern Grower Alliance (NGA) has been involved in numerous field trials since 2007, in collaboration NSW DPI, evaluating the impact of crown rot on a range of winter-cereal crop types and varieties.

This work has greatly improved the understanding of crown rot impact and variety tolerance, but also indicates that growers may be suffering significant yield losses from another 'disease' that often goes unnoticed.

Although the trials were not designed to focus on nematodes, a convincing trend was apparent after 2008 that indicated *P. thornei* was having a frequent and large impact on wheat variety yield. [30]

Where *Pt* combines with high levels of crown rot (a common scenario), yield losses can be exacerbated if varieties are susceptible to *Pt*. Instead of a 10% yield loss from *Pt* in a susceptible variety it could be 30–50% if crown rot is combined with a *Pt*-intolerant variety (Photo 4).

The research has also shown that not only does *Pt* cause high yield loss in susceptible varieties, but *Pt* numbers can increase much faster than in an area in which tolerant varieties are growing. These increased *Pt* numbers can lead to even greater damage in future crops. [31]

Photo 4: *Grass plant showing both parasitic nematode damage to roots and crown rot in above ground tissues.*

Source: NCSU

VIDEOS

WATCH : GCTV9: Crown rot and root-lesion nematode

29 T Dixon (2013) Balancing Crown rot and nematodes in wheat. Ground Cover Issue 104, May–June 2013. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-104-May-June-2013/Balancing-crown-rot-and-nematodes-in-wheat

30 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? GRDC Update Paper, 16 July 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Managing-root-lesion-nematodes-how-important-are-crop-and-variety-choice

31 B Freebairn (2011) Nematodes and crown rot: a costly union. Ground Cover Issue 91, March–April 2011, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union

8.3.1 Management

Variety choice is the key management option when it comes to managing *Pt* risk. However, when it comes to crown rot management, although varieties have some impact, rotation and stubble management are by far the most important management tools. Lupin is considered a break-crop for RLN and crown rot. RLNs, especially *Pt*, need to be taken far more seriously and better factored into crop rotation considerations as well as variety choice. [32]

Soil testing

Predicta B services can test for crown rot.

Crown Analytical Services has the first Australian commercial test for crown rot based on five years of laboratory research.

The frequency of the disease has increased in recent years due to continuous cropping of wheat. Crown rot causes significant yield losses. Some of the current strategies for management of the disease are to control grass hosts prior to cropping, rotate susceptible cereals with non-host break crops, burn infected stubble and grow tolerant wheat varieties.

Therefore, it is very important for crown rot testing to be carried out on a paddock. It allows for growers and consultants to determine if there is crown rot present in a paddock and if so, how severe it is. An informed decision can then be made regarding crop choice and farming system.

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

Crown Analytical Services provides sample bags and postage paid packs. Go to Protocol to better understand the process, or Contact Crown Analytical services.

Varietal choice

Crop rotation and variety choice are the important factors in protection against both diseases. Choosing a variety solely on crown rot resistance is not critical, especially if appropriate management techniques have been carried out, but choice of variety is crucial when it comes to RLN tolerance.

Further research into varietal tolerance to crown rot and nematodes has revealed that choosing a variety is difficult. Determining the relative tolerance of varieties to crown rot is complex as it can be significantly influenced by background inoculum levels, RLN populations, differential variety tolerance to *Pn* versus *Pt* and varietal interaction with the expression of crown rot. Other soil-borne pathogens such as *Bipolaris sorokiniana*, which causes common root rot, also need to be accounted for in the interaction between crown rot and varieties. Starting soil water, in-crop rainfall, relative biomass production, sowing date and resulting variety phenology in respect to moisture and/or temperature stress during grainfill can all differentially influence the expression of crown rot in different varieties. [33]

VIDEOS

WATCH : Over the Fence North: Drew Penberthy

32 B Freebairn (2011) Nematodes and crown rot: a costly union. Ground Cover Issue 91, March–April 2011, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union

33 S Simpfendorfer, M Gardner, G Brooke, L Jenkins (2014) Crown rot and nematodes—are you growing the right variety? GRDC Update Papers 6 March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Crown-rot-and-nematodes

Diseases

Key messages

- The most serious diseases in lupin are Anthracnose, Brown leaf spot, Pleiochaeta root rot, Phomopsis and Sclerotinia. Viruses can also be damaging to lupin crops.
- Only sowing high quality, disease-free seed is the first step in reducing the risk of disease in lupin crops.
- Have seed tested for germination, seed size and presence of Cucumber Mosaic Virus and Anthracnose.
- Crop rotation is also important for reducing inoculum in the paddock and reducing the risk of yield loss due to disease.
- Seed treatments can help to reduce the risk of disease in areas with a long history of growing lupin.
- Know the history of disease in each paddock and monitor crops according to disease incidence at each growth stage.

Lupins are susceptible to a wide range of diseases. Roots, hypocotyls, stems, pods and seeds of lupin are all subject to infection by disease organisms. Several of these diseases have the capacity to cause catastrophic losses, but this is rare if management guidelines are followed. Several diseases can infect lupin during the late vegetative and early reproductive stages of growth and can cause yield losses. Depending on the disease in question, inoculum can be carried in soil, seed, stubble, on green regrowth or by insect vectors. Therefore, an integrated approach to disease management is required. [1]

The major *diseases* of lupin are described below and include:

- Seedling diseases
  - » Pleiochaeta root rot, Phytophthora root rot, Rhizoctonia bare patch, Pythium root rot
- Foliar diseases
  - » Anthracnose, Brown leaf spot, Phomopsis, Sclerotinia, Botrytis grey mould
- Viruses
  - » Cucumber Mosaic Virus, Bean Yellow Mosaic Virus

9.3.1 Integrated disease management

To reduce the risk of disease damage each year, growers need to implement an integrated disease management strategy. This strategy should include sowing healthy seed, knowing the variety resistance rating, using seed dressings, paddock selection and actively monitoring crops for insect vectors and diseases to ensure timely foliar fungicide and/or insecticide application. Key steps in the integrated management of lupin diseases include crop rotation, stubble management, fungicide or pesticide application, variety selection and seed testing.

Variety choice

Yield and marketability, along with disease resistance, are the major factors to consider in variety choice. Resistant varieties are not immune to that disease, and may suffer some production losses or grain quality damage under high disease pressure (Table 1).

1 I Pritchard (2017) Lupin essentials – growing a successful lupin crop. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4

Table 1: *Lupin disease response. VS=Very susceptible, S=Susceptible, MS=Moderately susceptible, MR=Moderately resistant, R=Resistant.*

	Disease					
Variety	Brown Leaf Spot	Pleiochaeta root rot	Phomopsis stem infection	CMV # seed transmission	BYMV #	Anthracnose resistance
Narrow-leaf						
Jenabillup⦇	MR	R	MS	MS-MR	MR	MS
Jindalee⦇	MR	MR	R	SS	S	MS
Mandelup⦇	MS	R	R	MS	MS	MR
PBA Barlock⦇	MS	R	MR	MR	MS	R
PBA Gunyidi⦇	MS	R	R	MS-MR	MS-MR	MR
PBA Jurien⦇	MS	R	R	MS-MR	MS	R
Quilinock	MS	R	MS-MR	MR	-	VS
Wonga⦇	MS	S	R	R	MS	R
Albus						
Kiev Mutant	R	VS	R	Immune	n.d	VS
Luxor⦇	R	R	R	Immune	n.d	VS
Rosetta⦇	R	MR	R	Immune	n.d	VS
Ultra	R	S	R	Immune	n.d	VS

Source: NSW DPI

Seed quality

Many important diseases of pulses can be seed-borne. Select seed of the highest possible purity, germination and disease free status. Only seed that is pathogen-free should be used for sowing. Testing seed before sowing will identify potential disease problems and allow steps to be taken to reduce the disease risk. Laboratory testing is usually required, as infected seed may have no visible disease symptoms. Seed retained on-farm should be from the 'cleanest' paddock or section. Select the area early, apply fungicides at podding and harvest the seed crop ahead of other paddocks to prevent contamination from potentially diseased crops.

If seed is more than one year old, frosted, weather damaged or diseased, its germination and vigour may have deteriorated. This may increase the crop's susceptibility to disease attack. Re-test seed for germination percentage before sowing if retained in silos for more than one year. [2]

Disease monitoring

Disease impact is greatly reduced when a fully integrated disease management program is initiated before seeding and maintained through the growing season. A crop is considered to be at high risk if a susceptible variety is grown, crop rotation is tight or where all integrated management strategies cannot be followed. [3]

MORE INFORMATION

Seed health testing in pulse crops

2 Pulse Australia (2015) Australian Pulse Bulletin: Chickpea integrated disease management. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies

3 Pulse Australia (2015) Australian Pulse Bulletin: Chickpea integrated disease management. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies

Crops should be monitored for foliar disease symptoms throughout the growing season. Take the time to conduct thorough visual inspections of leaves, buds and stems for any signs of disease.

Root and hypocotyl diseases can be significant problems in lupin crops, reducing stand density, plant vigour and yield. Root rot occurs in nearly all narrow-leafed lupin paddocks but in the majority of paddocks root disease has only a small impact on crop development. However, in paddocks where high levels of root rot occurs, plant establishment and seedling vigour are significantly affected. *Pleiochaeta setosa* and *Rhizoctonia solani* are the pathogens commonly associated with root or hypocotyl infection of lupins.

MORE INFORMATION

Monitoring root disease

PreDicta B Northern region – Know before you sow

When a root disease is present in a crop very little can be done to manage it in that cropping season. It is therefore vital that the cause is correctly identified to allow appropriate management to take place before sowing the next lupin crop. Correct identification can be made from symptoms on the root and hypocotyl of affected plants. Above ground symptoms such as poor emergence, patches in crops, uneven and stunted growth, yellowing of plants and wilting or death under water stress, particularly at flowering and grain fill, can indicate the presence of root disorders. These above ground symptoms are rarely diagnostic as many biotic and abiotic disorders will have similar above ground expression. [4]

More detail on the signs and symptoms of root and foliar diseases is provided in the following sections.

Though, plants can be dug up during the growing season, it is recommended that growers test their soil before sowing, to minimise the risk of yield loss.

The simplest way for growers to identify potential root disease risks is to use a PreDicta B soil test prior to sowing.

PreDicta B soil testing

PreDicta B (B = broadacre) is a DNA-based soil testing service to assist grain producers to identify which soil-borne pathogens pose a significant risk to their crops prior to seeding so steps can be taken to minimise risk of yield loss. This test identifies and quantifies all of the important soil borne diseases.

Growers can access PreDicta B through a SARDI accredited agronomist, who will organise sampling, interpret the results and give advice on management options to reduce the risk of yield loss.

SARDI Molecular Diagnostic Centre processes PreDicta B samples weekly between February to mid-May prior to crops being sown. Samples are processed less frequently throughout the rest of the year.

4 G Thomas, D Huberli (2016) Lupin root disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management

Example foliar fungicide trade name and manufacturer	Active Ingredient	Harvest withholding period (WHP) – weeks/days		Rate to apply per hectare (L/ha or kg/ha)	Cost of product per litre ($)	Size of pack (kg or L – range of pack sizes)
		Harvest	Grazing			
Bravo® Weather Silk - Syngenta	Chlorothalonil (720 g/L)	7 days	Do not graze	1.4–2.3 L	13.20	10–100 L
						5–200 L
Barrack® Betterstick – Crop Care	Chlorothalonil (720 g/L)	7 days	Do not graze	1.4–2.3 L (Faba Beans) 1.0–2.0 L (Chickpeas)	13.20	10–100 L
						5–200 L
Barrack®720 – Crop Care Unite®720 - Nufarm	Chlorothalonil (720 g/L)	14 days	14 days	14–2.3 L (Faba beans) 1.0 L-2.0 L (Chickpeas)	13.20	5–200 L
						5–1000 L
Echo®900 Fungicide - Sipcam	Chlorothalonil (900 g/kg)	14 days	14 days	1.2 kg-1.9 kg (faba beans) 0.8–1.6 kg (chickpeas)	17.55	1–20 kg
Roval®Liquid – FMC Iprodione Liquid 250 - Cheminova	Iprodione (250 g/L)	42 days	42 days	2.0 L	18.30	5–1000 L
Dithane® Rainshield Neo Tec Fungicide – Dow AgroSciences	Mancozeb (750 g/kg)	28 days	14 days	1.0–2.2 kg	9.50	20 kg
Manzate® DF - Sipcam	Mancozeb (750 g/kg)	28 days	14 days	1.0–2.2 kg	9.50	10–20 kg
Penncozeb® 750 DF- Nufarm	Mancozeb (750 g/kg)	28 days	14 days	1.0–2.2 kg	10.45	10 & 20 kg
Polyram® DF – Nufarm	Metiram (700 g/kg)	6 weeks	21 days	1.0–2.2 kg	13.20	15 kg
Fortress® 500 – Crop Care Sumisclex® Broadacre - Sumitomo	Procymidone (500 g/L)	Canola not required	9 weeks	1.0 L (canola) 0.5 L (faba bean)	49.55	5–10 L
		Faba beans 9 days	Not stated			20 L
Prosaro®420 SC – Bayer CropScience	Prothioconazole (210 g/L) + tebuconazole (210 g/L)	Not required	14 days	375–450 mL/ha	77.00	5–20 L
Folicur® 430 SC – Bayer CropScience Hornet® - Nufarm	Tebuconazole (430 g/L)	3 days	3 days	145 mL	13.20	Folicur 5–60 L
		PER13752 21 days	PER13752 14 days			Hornet 20 L
Triadimefon 12SEC - Cheminova	Triadimefon (125 g/L)	14 days	Not stated	500 mL	6.00	5–1000 L

MORE INFORMATION

Field Crop Diseases Manual online

GrowNotes Alert™

9.3.2 Useful tools

Foliar diseases – the Ute guide

GRDC UteGuides App is a mobile information resource for farmers and agronomists working in the Australian Grains Industry. It provides searchable library topics with extensive high resolution images on subjects relevant to grain-growers. It compliments and extends GRDC's paper-based Ute Guide series by linking all resources under a single App.

The GRDC Foliar diseases Ute Guide provides disease descriptions and images relevant to each crop.

Crop Disease Au app

The app Crop Disease Au, developed by the National Variety Trials, allows the user to quickly:

- Identify crop diseases.
- Compare disease-resistance ratings for cereal, pulse and oilseed varieties.
- Potentially, facilitate the early detection of exotic crop diseases.

The app brings together disease-resistance ratings, disease information and also features an extensive library of quality images that make it easier for growers to diagnose crop diseases and implement timely management strategies. Live feeds from the Australian National Variety Trials (NVT) database means the apps is always up to date with the latest varieties.

If a disease cannot be identified there is also a function that allows the user to take a photo of their crop and email it to a friend or an adviser.

The precursor for this app was the Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR) Crop Disease app developed by a team of grains pathologists. Crop Disease Au functions similarly to the old app, but provides information for all Australian grain-growing regions.

9.3.3 GrowNotes Alert™

GrowNotes Alert is a free nationwide system for delivering urgent, actionable and economically important pest, disease weed and biosecurity issues directly to you, the grower, adviser and industry body, the way you want. Real-time information from experts across Australia, to help growers increase profitability.

A GrowNotes Alert notification can be delivered via SMS, email, web portal or via the iOS App. There are also three by dedicated regional Twitter handles – @GNAlertNorth, @GNAlertSouth and @GNAlertWest – that can also be followed.

The urgency with which alerts are delivered can help reduce the impact of disease, pest and weed costs. GrowNotes Alert improves the relevance, reliability, speed and coverage of notifications on the incidence, prevalence and distribution of these issues within all Australian grain growing regions.

9.1 Pleiochaeta root rot

Pleiochaeta root rot (PRR) is the root-attacking form of the brown leaf spot pathogen (*Pleiochaeta setosa*) and infects albus lupin. It can kill large numbers of plants within a paddock. Good crop rotation, with at least a 4-year break between lupin crops, is essential for effective control. [5]

Spores produced on fallen brown spot infected leaves are incorporated into the top few centimetres of soil where they remain until the next lupin crop is sown. This fungus is commonly associated with root rot lesions but rarely causes major crop

5 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

losses in current farming systems. Soil-borne spores can infect the taproot of albus plants causing stunting and premature death. [6]

9.1.1 Varietal resistance or tolerance

Albus lupin is reasonably tolerant to PRR when grown on red-brown loamy soils. However, older varieties are susceptible to PRR caused by the same fungus, *Pleiochaeta setosa*.

Luxor⦶ is rated R and Rosetta⦶ rated MR to the disease.

9.1.2 Symptoms

Affected plants are often widespread within a paddock and above ground symptoms include wilting and death of seedlings or generally poor growth of plants (Photo 1). Infection produces dark brown lesions on the tap and lateral roots leading to stripping of the outer layer of the root and in severe cases complete rotting of the root (Photo 2). Tap roots are susceptible for 6–8 weeks after germination; however, new lateral roots are susceptible whenever they emerge during the season. [7]

Photo 1: *Plant damage varies with depth of pleiochaeta spores and seed.*

Source: DAFWA

6 G Thomas, D Huberli (2016) Lupin root disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management

7 G Thomas, D Huberli (2016) Lupin root disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management

MORE INFORMATION

Diagnosing pleiochaeta root rot in narrow-leafed lupins

Photo 2: *Pleiochaeta root rot on Kiev Mutant seedlings grown in a growth-room disease-screening experiment.*

Photo: Raymond Cowley, Source: NSW DPI

9.1.3 Management of Pleiochaeta root rot

Key points:

- Reduced or minimum tillage sowing operations reduce the incorporation of spores into the rooting zone of the soil profile.
- Deeper sowing places the emerging roots below the spore laden soil layer, this is particularly important with sowing systems utilising tillage systems.
- Rotation with non-host crops (for example, cereals, canola, pasture) reduces the concentration of soil borne spores.
- Reducing brown spot in preceding lupin crops can reduce the amount of spores returned to soil. [8]

In areas where lupin has been grown for a long time, seed should be treated with either iprodione (for example, Rovral®) or procymidone (for example, Sumisclex®) to reduce the risk of pleiochaeta root rot.

Disease management is the same as for Brown leaf spot.

The GRDC Foliar diseases Ute Guide provides disease descriptions and images relevant to each crop.

9.2 Phytophthora root rot

Phytophthora root rot (sudden death) can cause sudden death of lupin plants during flowering and pod filling. It is serious disease in years when late winter and early spring are wet, and plants suddenly wilt and die around pod set stage. Outbreaks of this disease were widespread in 2016 in southern NSW due to above average rainfall and wet soil conditions.

The disease can occur as individual plants or patches within a crop. In narrow-leaf lupin, an undescribed species of Phytophthora causes the disease. In albus lupin the disease is caused by *Phytophthora cryptogea*. Disease management is difficult because of the extended period of survival of the fungus in the soil. Methods to

8 G Thomas, D Huberli (2016) Lupin root disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management

minimise the occurrence of the disease include crop rotation and avoiding paddocks with a known water-logging problem. [9]

9.2.1 Varietal resistance or tolerance

There is no date for varietal resistance or tolerance for Phytophthora root rot.

9.2.2 Damage caused by Phytophthora root rot

Phytophthora root rot was first observed in NSW in 1993, when large areas of apparently healthy lupin crops suddenly died. Since that time this condition has be observed annually across southern NSW, with varying degrees of crop damage, ranging from scattered plants to total crop losses in some instances. [10]

9.2.3 Symptoms

The sudden wilting and death of lupin plants within days during pod filling is indicative of this disease. Leaves suddenly turn yellow and drop, often within a 24 hour period, and a dark brown sunken lesion may extend from the base and often up one side of the stem. Infected plants are found to have a rotted taproot when pulled out of the ground. The taproot is woody in appearance with little outer tissue remaining and with few, if any, lateral roots (Photo 3). The pattern of distribution within a paddock can vary from single scattered plants to large areas of crop, often in lowlying areas of paddocks. Plants fail to fill pods or produce small seed. [11]

Photo 3: *Lupin plants with typical rotted root system, and lower stem lesions.*

Source: CropPro

9.2.4 Conditions favouring development

There are two essential prerequisites for disease development. Firstly, soil temperatures must be increasing and above approximately 15°C. This explains why the disease is not seen early in the season during the cooler winter months. Once

9 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

10 D Carpenter (2002) Pulse point 17: Phytophthora root rot of lupins. NSW DPI, GRDC. http://archive.dpi.nsw.gov.au/__data/assets/pdf_file/0019/157411/pulse-point-17.pdf

11 D Carpenter (2002) Pulse point 17: Phytophthora root rot of lupins. NSW DPI, GRDC. http://archive.dpi.nsw.gov.au/__data/assets/pdf_file/0019/157411/pulse-point-17.pdf

temperatures rise, infection occurs, the taproot is subsequently rotted, and plants suddenly wilt and die. Often this occurs around early pod fill when plants are drawing upon soil water from deeper in the profile, but the infected root system cannot sustain the growing plant. The second requirement is a period of flooding or waterlogging, although this appears to be unnecessary in close rotations where high levels of soil inoculum have had a chance to build up.

Waterlogging is often directly linked to the presence of hardpans or plough-pans. These are compacted layers within the soil profile which can form just below the zone of cultivation as a result of many years of cultivation. They are often impenetrable to plant roots and water. If hard pans are present, perched water tables can occur during and following periods of heavy or prolonged rainfall, allowing root infection to occur. [12]

9.2.5 Management of Phytophthora root rot

The most effective practice that can be recommended would be to avoid paddocks that are known to have a hardpan problem, since it appears that a period of waterlogging can be important for infection to occur. Hardpans can be identified by simply pushing a spade or shovel into the soil. A layer of resistance is felt where a hardpan is present. Alternatively dig up some plants and observe the root growth. The regular occurrence of distorted taproots shaped like an 'L' indicate a hardpan. Consult your local agronomist to develop a strategy to manage them. In addition, because the species and host range of Phytophthora is mostly unknown, it is not possible to recommend suitable crop rotations to minimise disease impact. [13]

MORE INFORMATION

Phytophthora root rot of lupins

Growers should also avoid sowing into paddocks with a long history of medic or clover pastures as these crops increase the likelihood of Phytophthora in the soil. Chickpeas are also very susceptible to damage from this disease.

The GRDC Foliar diseases Ute Guide provides disease descriptions and images relevant to each crop.

9.3 Rhizoctonia bare patch

Rhizoctonia bare patch is a seedling disease caused by the fungus *Rhizoctonia solani* (ZG1). It has a wide host range and attacks most crop, pasture and weed species. The fungus grows in the soil and colonises either living plant tissue or dead organic material. Rhizoctonia causes crop damage by pruning the root system, which results in water and nutrient stress to the plant. It can survive fallow periods as a saprophyte in plant residues in soil. With the onset of opening rains in autumn the fungus grows rapidly within the soil to infect young seedlings. [14]

9.3.1 Varietal resistance or tolerance

There are no resistant or tolerant varieties available.

9.3.2 Damage caused by Rhizoctonia

Yield losses from Rhizoctonia are proportional to the total area of the patches and can average up to 50%. It is estimated that Rhizoctonia in southern Australia costs $77 million each year in lost production.

12 D Carpenter (2002) Pulse point 17: Phytophthora root rot of lupins. NSW DPI, GRDC. http://archive.dpi.nsw.gov.au/__data/assets/pdf_file/0019/157411/pulse-point-17.pdf

13 D Carpenter (2002) Pulse point 17: Phytophthora root rot of lupins. NSW DPI, GRDC. http://archive.dpi.nsw.gov.au/__data/assets/pdf_file/0019/157411/pulse-point-17.pdf

14 G Thomas, D Huberli (2016) Lupin root disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management

9.3.3 Symptoms

Above ground symptoms appear as roughly circular patches with distinct edges, often elongated along the direction of cultivation, which become apparent 3–4 weeks after sowing (Photo 4). The fungus has a wide host range and similar patches may be evident in other crops grown in the same paddock. The bare patches vary in size from less than half a metre up to several metres across. Depending on the severity of disease, plants within patches can be stunted or dead. When plants are dug up, the tap root and lateral roots are pinched off by dark brown lesions, often giving a 'spear tipped' appearance (Photo 5). [15]

Photo 4: *Rhizoctonia bare patch in lupin crop.*

Source: DAFWA

Photo 5: *Rhizoctonia affected lupin seedling.*

Source: DAFWA

MORE INFORMATION

Diagnosing Rhizoctonia bare patch in grain legumes

15 G Thomas, D Huberli (2016) Lupin root disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management

9.3.4 Conditions favouring development

With the increased adoption of conservation tillage, this disease has become much more widespread, as cultivation had provided some control of Rhizoctonia by breaking up the network of hyphae in the soil. The ability for Rhizoctonia saprophytes to survive in soil is strongly influenced by the soil conditions; e.g. soil type, fertility, moisture, temperature, biological activity. This is why the disease can appear 'out of the blue' in some paddocks and why some seasons are much worse than others. This disease occurs on most soil types, although appears most common on sandy soils. It affects all lupin varieties and species.

9.3.5 Management of Rhizoctonia bare patch

Key points:

- Rhizoctonia bare patch has a wide host range and cannot be controlled by rotating crops.
- Tillage to a depth of 10–15 centimetres (cm) at about the time of sowing reduces the number and severity of patches. Modification of seeding machinery to cultivate 5–10 cm below the sowing depth will provide effective disease control in a direct drilled crops
- Patches can also be controlled by deep ripping (25–30 cm) immediately before or after seeding.
- Seed or in-furrow fungicides are not yet registered for lupins.
- Varietal selection also has little efficacy in reducing the risk of Rhizoctonia disease. [16]

Rhizoctonia cannot be eliminated but can be suppressed to a level that doesn't cause economic loss. Rhizoctonia root rot is difficult to control because:

- the fungus has a wide host range; i.e. limited rotational controls;
- there are no resistant cultivars; and
- the fungus can grow and survive in the soil on organic residues without a live plant host – this is termed 'saprophytic ability'.

Reduce inoculum

Deep cultivation at sowing with a narrow tine below seed (10–15 centimetre (cm)) or deep ripping (25–30 cm) immediately prior to sowing is the most effective methods of reducing damage caused by this disease. The cultivation reduces the incidence and impact of the disease by disturbing fungal growth within the soil and encouraging better root growth. Cultivation one to two weeks prior to sowing can also be very effective.

In seasons with an early break, remove volunteer plant growth as soon as possible, using either cultivation or herbicides.

Help roots avoid inoculum through encouraging faster early growth

Ensuring good crop growth through adequate plant nutrition and avoiding herbicide damage to roots will reduce the impact of this disease.

Rhizoctonia can only attack very young plant roots so anything that increases early root growth can significantly reduce disease. Ensure to provide adequate nutrition (particularly phosphorus and zinc). Sow early into warm soils where possible as this allows for increased root growth early in the season, increasing the plants ability to tolerate disease. Avoid SU herbicides, both pre and post-sowing applications and residues from the previous season. Some seed coatings may increase rate of early root growth and provide some reduction in root damage through suppression of

16 G Thomas, D Huberli (2016) Lupin root disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management

MORE INFORMATION

Rhizoctonia Fact sheet.

Rhizoctonia bare patch. Though it is important to note that fungicide seed dressing (registered for brown spot or anthracnose) are not effective against Rhizoctonia. [17]

The GRDC Foliar diseases Ute Guide provides disease descriptions and images relevant to each crop.

9.4 Pythium root rot

The root pathogen Pythium is widely spread across cropping soils and is more prevalent in areas with an annual rainfall above 350 mm. Pythium fungi can cause root rot in lupins. While at least eight species of Pythium have been identified under rotations including canola, cereals and pulses, *Pythium irregulare* and its close relatives were found to be the dominant species. The balance of the species was found to change under different crop rotations.

9.4.1 Damage caused by Pythium

The plant pathogen infects germinating seeds, root tips and strips away fine rootlets and root hairs. Pythium causes seedling damping off and root rot. All major crop and pasture species grown across Australia can host and be infected by Pythium.

Pythium grows rapidly, producing large numbers of spores on growing plant tissues and on fresh plant material added to soil, such as stubble and weeds killed by herbicides or tillage. These spores enable Pythium to re-infect growing roots rapidly and continuously. Consequently, crops can experience repeated 'waves' of Pythium infection throughout the growing season. This contrasts to the slower inoculum build-up attributed to other fungal root diseases such as take-all and Rhizoctonia. The weakened plant is then more vulnerable to infection by these other fungal pathogens. Plants may recover from early infection, especially where nutrition is adequate, but slowing plant development results in crop yield potential being significantly reduced. [18]

9.4.2 Symptoms

In the field Pythium is frequently misdiagnosed as Rhizoctonia.

Seedling damping-off, failure to thrive and yield decline are all symptoms or potential results from Pythium infection. Infected seedlings appear spindly and stunted, and in cereals the first true leaf is often short, twisted and cupped. Pythium is often distributed relatively evenly in soils. This means that in the absence of a protective treatment all plants are affected by Pythium to a similar extent and that unless severe, infection goes undetected.

Consequently, diagnosis of Pythium root rot based on above-ground symptoms is difficult and when the disease is moderate to severe, is often misdiagnosed as Rhizoctonia damage. The effects of Pythium root rot are therefore often underestimated.

Pythium-infected root systems appear stunted with few lateral roots. Infected roots develop a black rot and hypocotyls can develop water soaked lesions. They show soft, yellow to light brown colouration in infected areas especially near the tips. Finer 'feeder roots' are often lost, the outer layers rotting away and exposing the central vascular tissues to give the appearance of Rhizoctonia-like 'spear points' (Photo 6).

Infection can kill emerging seedlings or create weak and stunted plants that wilt once the stem begins to elongate. [19]

17 GRDC (2008) Rhizoctonia Factsheet. https://grdc.com.au/__data/assets/pdf_file/0014/222143/rhizoctonia-factsheet.pdf.pdf

18 P Harvey (2010) Pythium root rot- Factsheet. GRDC. www.grdc.com.au/GRDC-FS-PythiumRootRot

19 P Harvey (2010) Pythium root rot- Factsheet. GRDC. www.grdc.com.au/GRDC-FS-PythiumRootRot

Photo 6: *Below ground symptoms of Pythium root rot. Carefully extracted and washed roots show browning, evidence of root loss and rotting of the outer layers to give Rhizoctonia-like spear points.*

Source: GRDC

9.4.3 Conditions favouring development

Chemicals released from germinating seeds and emerging roots trigger Pythium to grow and attract it to the host, infection occurred as early as 24 to 48 hours after sowing into moist soil.

The prevalence of the disease is greater in acid-neutral soils with higher levels of organic matter and under reduced tillage systems.

Generally, infection mostly takes place when soil conditions favour the fungus, such as sowing into cold wet soil, most commonly on shallow duplex soils and other soils prone to sub-soil saturation. These soil conditions are often unfavourable for lupin production in the absence of Pythium root rot.

However, research has found that high rainfall or cold waterlogged soils are not a prerequisite for Pythium infection. High incidences of root rot were recorded in periods of drought, conditions not previously considered conducive to development of Pythium diseases. [20]

9.4.4 Management of Pythium root rot

Avoiding water-logging prone soils unfavourable for lupin production will minimise the risk of significant damage from this disease.

Crop rotation

Pythium is found in all Australia's crop environments and all crop and pasture species are susceptible to infection. Generally, such a wide host range suggests that crop rotations will not result in disease control. However, Crop species, and to a lesser extent varieties, show significant differences in their susceptibility to damage by Pythium and in their ability to 'carry over' inoculum. Consequently, research has shown that crop choice and frequency play a pivotal role in the build-up and decline of Pythium inoculum. Grain and pasture legumes and canola crops have been found

20 P Harvey (2010) Pythium root rot- Factsheet. GRDC. www.grdc.com.au/GRDC-FS-PythiumRootRot

to support larger populations of Pythium than cereals, with barley being the least susceptible.

Disease incidence was found to be significantly greater after long term pastures (legumes or mixed) and in less diverse rotations. For example, in a repetitive canola-wheat rotation, Pythium inoculum levels reduced under the wheat phase but this decline was smaller than the inoculum increase under the canola. Consequently, year-on-year inoculum levels were rising. In a more diverse rotation, especially those that included two nonconsecutive cereals, the increase in soil inoculum and root infection across the rotation was lower. Differences in the rate of inoculum change at these two sites relate to the types of Pythium species present and the varieties grown. Despite the contrasting soil pH and rainfall between the sites, the effects on Pythium levels were very similar, indicating that crop type was driving these changes.

Chemical control

Extensive field trials using a Pythium-selective seed dressing resulted in yield increases, especially in canola and pulses. These yield increases generally occurred in the absence of any improved crop emergence and with only partial (25 per cent reduction) in Pythium. Pythium-selective chemicals were more effective in the higher-diversity rotations, probably being related to the lower overall inoculum levels and disease pressures. Due to their relatively short window of activity (four to eight weeks), chemical seed treatments do not protect against on-going Pythium root attack. The pathogen's ability to rapidly produce large numbers of infective spores means that Pythium numbers can quickly recover as the season progresses. Based on this, yield benefits achieved with chemical seed dressings are primarily associated with improved seedling vigour and early crop growth. More effective, sustained disease control throughout the growing season can lead to further improvements in grain yields. [21]

MORE INFORMATION

Pythium root rot - Factsheet

9.5 Fusarium

Fusarium wilt (*Fusarium spp*.) is a soil-borne fungal pathogen that can cause major yield loss. Little is currently known of the disease in Australia, including which species are responsible. The disease is spread through the movement of soil, crop debris or vehicles, machinery and shoes contaminated with soil from fields where the pathogen is present.

Fusarium wilt is becoming an increasing problem to mungbean growers across the Northern grains region and while it is often found at a low incidence (1–10%) in most paddocks, in recent years it has caused extensive damage (greater than 70% incidence) to several crops.

9.5.1 Symptoms

Both seedlings and older plants can be affected by the disease. Affected seedlings wilt and their lower roots rot and may develop a basal rot on stems. If infection occurs in older plants, the leaves will wilt and a discolouration of the xylem tissue is evident when the stem is cut longitudinally.

The symptoms of *Fusarium* can easily be confused with Phytophthora root rot, charcoal rot, fungicide burn (particularly triazoles) and nutrient deficiencies. [22]

9.5.2 Conditions favouring development

Fusarium wilt often occurs in paddocks experiencing stressful conditions, such as excess water. Heavy clay soils are more often affected, particularly on the edge of paddocks and in low lying areas. [23]

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21 P Harvey (2010) Pythium root rot- Factsheet. GRDC. www.grdc.com.au/GRDC-FS-PythiumRootRot

22 Plant Health Australia (2015) Sudden death syndrome of soybean. http://www.planthealthaustralia.com.au/wp-content/uploads/2015/01/Sudden-death-syndrome-of-soybean-FS.pdf

23 S Jefferey (2016) Fusarium wilt raises its head in mungbean crops. GRDC. https://grdc.com.au/news-and-media/news-and-media-releases/north/2016/03/fusarium-wilt-raises-its-head-in-mungbean-crops

9.5.3 Management

Control of fusarium wilt is difficult once established in a field. The best control option for this disease is resistant cultivars, but these are currently not available. The main control options for growers in Australia include avoidance of infected fields, planting in cooler months of the year, adopting a strict farm hygiene plan and growing non-susceptible crops.

Management options for growers must include maintaining a farm hygiene policy, especially when moving from infected ground to a clean property or block. Growers should soil movement by any means from one property to the next. The fungus is easily transferred in soil. Restrict the movement of machinery such as tractors and wash them before going from an infected paddock to a clean paddock. [24]

9.6 Lupin anthracnose (*Colletotrichum lupini*)

Lupin anthracnose (*Colletotrichum lupini*) is a fungal disease of lupin plants, causing the stems to twist and break and dead patches to appear on the leaves and pods. Lupin anthracnose may lead to complete crop losses in susceptible varieties. Anthracnose is more likely to severely damage albus lupin than narrow-leafed lupin. Anthracnose occurs in commercial lupin crops throughout Western Australia and South Australia, and was first detected in New South Wales in 2016. [25]

The disease is specific to lupin species only and does not affect any other pulse crops including field peas, faba beans, chickpeas or lentils. The fungus survives on infected lupin stubble and can be carried on or within infected seed, which is the main means of disease spread. Infected seed will give rise to infected seedlings the following year and initiate the disease. The fungus does not survive in the soil. [26]

Anthracnose in NSW

In October 2016, lupin anthracnose was detected for the first time in commercial crops in the eastern Riverina region of NSW. Currently the disease is confined to a small number of properties, with restrictions in place. Lupin production can continue for the remainder of NSW outside the restriction zones.

Natural hosts of lupin anthracnose are not established in NSW and as the infected crops were relatively isolated, successful eradication of the disease was considered possible and an eradication program is now in place.

All lupins crops found to be infected with lupin anthracnose in 2016 have been either destroyed or sold under special conditions to prevent further spread of the disease.

The eradication program also includes the creation of the lupin anthracnose biosecurity zone (LABZ) within which special conditions apply to the growing of ornamental and commercial lupins.

The lupin anthracnose biosecurity zone

The lupin anthracnose biosecurity zone (LABZ) was created under the Plant Diseases Act 1924 in November 2016 and consists of the three Local Government Areas of Cootamundra/ Gundagai, Junee and Coolamon.

The special conditions include restrictions on the growing and sale of certain lupins within the zone. See Primefact 1499 Lupin anthracnose biosecurity zone for more information. The legislation is to remain in place until such time as the disease has been successfully eradicated or otherwise.

MORE INFORMATION

Exotic pest alert: Lupin anthracnose

Lupin anthracnose biosecurity zone

Plant Diseases (Lupin Anthracnose Biosecurity Zone) Order 2016

24 A Watson, A Yousiph, E Liew, J Duff (2009) Primefacts: Management options for fusarium wilt of snowpeas. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/228036/Management-options-for-Fusarium-wilt-of-snow-peas.pdf

25 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

26 K Lindebeck, K Moore, M Richards, G O'Connor (2017) GRDC Update Papers: The Watch outs for pulse diseases in 2017. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/The-watch-outs-for-pulse-diseases-in-2017

9.6.1 Varietal resistance or tolerance

Wonga⫽, PBA Jurien⫽ and PBA Barlock⫽ are R whilst PBA Gunyidi⫽ (MR-R) and Mandelup⫽ (MR) are slightly more susceptible. All other narrow-leaf and albus lupin varieties are very susceptible to anthracnose (Table 1). [27]

9.6.2 Damage caused by Anthracnose

Lupin Anthracnose damages stems, leaves and pods, which can reduce grain yield. The disease has potential to cause complete crop losses in susceptible varieties.

9.6.3 Symptoms

Symptoms of lupin anthracnose can be seen on all above ground parts of the host plant. If infection occurs early in the season lesions can be found on seedlings.

The most obvious symptom in lupins is bending and twisting of stems (shepherd's crook), which is particularly noticeable when the crop is flowering (Photo 7). The bending of stems is due to the formation of lesions within the crook of the bend causing collapse down one side.

Photo 7: *Infected lupin plants with stem lesions and bending.*

Source: NSW DPI, Photo: Geoff Thomas

Another symptom is oval shaped lesions which occur where the stems are bent over. Lesions can be up to 2 cm in length and contain a beige pink spore mass with an oozy appearance. Both main stems and lateral branches can be affected, with similar symptoms also found on leaf petioles.

Later in the season as the disease progresses, similar lesions can be seen to develop on the pods, distorting and twisting them (Photo 8). Infection of pods can lead to complete pod loss, and the production of infected seed. Infected seeds can be malformed, and have brown lesions on the surface (Photo 9). Seeds can also be infected without showing visible symptoms. [28]

27 K Lindebeck, K Moore, M Richards, G O'Connor (2017) GRDC Update Papers: The Watch outs for pulse diseases in 2017. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/The-watch-outs-for-pulse-diseases-in-2017

28 NSW DPI (2015) PrimeFact: Exotic pest alert – Lupin Anthracnose. https://www.dpi.nsw.gov.au/biosecurity/plant/exotic-pest-alerts/pulses/lupin-anthracnose

Photo 8: *Lupin pod showing lesion symptoms.*

Source: NSW DPI, Photo: Geoff Thomas

Photo 9: *Infected lupin seeds with brown lesions.*

Source: NSW DPI, Photo: Geoff Thomas

Symptoms become most obvious when crops come into the reproductive phase and start flowering and podding. The disease attacks the soft plant tissue at the growing points (including stem tips, flowering spikes and pods) and works downwards into the crop canopy.

Anthracnose will develop in patches or 'hotspots' within the crop. As the disease is spread through rain splash of spores, patches of deformed plants will form within the crop as the disease spreads following rainfall events. [29]

9.6.4 Conditions favouring development

Anthracnose is favoured by warm wet conditions and therefore the greatest risk of disease is in high-medium rainfall areas.

Disease lifecycle

Initial infection occurs from the fungus carried on or in infected seed. Seedlings emerging from infected seed may develop lesions. Lesions produce an abundance of fungal spores which are spread through the crop by rain splash. The fungus can survive over summer on infected stubble and spores can be splashed to re-infect seedling lupins planted into infected stubble. Rain decreases the viability of the fungus on stubble making it less likely to survive through the following winter and spring conditions. In Western Australia, mixed pastures containing blue lupins are a potential source of inoculum for infection of commercial species.

Disease spread

Infected seeds are the main source of spread of lupin anthracnose. The fungus can survive for up to two years on lupin seed and possibly longer under some conditions. Lupin anthracnose can also be spread by infected stubble through rain splash, and movement of spores by contaminated machinery, vehicles, people, animals and fodder between lupin crops and cropping areas. [30]

9.6.5 Management of Anthracnose

Key points:

- Resistant varieties are available; these should be used in higher risk environments.
- Seed can be tested for the presence and quantity of anthracnose infection. Use of clean seed is ideal but in some circumstances (for example, resistant varieties or lower rainfall environment) low levels of seed infection can be tolerated.
- Thiram-based seed dressing fungicide will reduce disease transmission from infected seed.
- In high disease situations, registered foliar sprays applied at early podding on main stems and first order branches can be used to reduce yield loss. [31]

A **five-point management plan** is recommended for all lupin growers in NSW to prevent establishment and spread of the disease:

1. **Treat seed for sowing with a fungicide seed treatment containing thiram.** Seed transmission is the main form of disease spread and survival between seasons. Treating lupin seed for sowing with a fungicide seed dressing containing thiram can significantly reduce the chances of anthracnose developing and becoming established. Be aware that seed applied fungicides can be detrimental to rhizobia. The best approach is to treat seed with fungicide and allow to completely dry before applying the rhizobia shortly before sowing, with an increased rate of rhizobia to ensure survival.
2. **Separate this year's lupin crop away from last year's lupin stubble.** The anthracnose fungus can survive in infected lupin trash between seasons. New infections can arise if infected lupin trash comes into contact with new season's lupin crops. Prevent transmission from infected stubble by separating this year's lupin crop away from last year's lupin stubble.

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29 K Lindebeck, K Moore, M Richards, G O'Connor (2017) GRDC Update Papers: The Watch outs for pulse diseases in 2017. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/The-watch-outs-for-pulse-diseases-in-2017

30 NSW DPI (2015) PrimeFact: Exotic pest alert – Lupin Anthracnose. https://www.dpi.nsw.gov.au/biosecurity/plant/exotic-pest-alerts/pulses/lupin-anthracnose

31 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

3. **Control volunteer lupins on your property.** Volunteer lupins can be an additional source of infection for new season's crops. Volunteer lupins can arise from within previous year's lupin paddocks or from feeding lupin seed to stock over summer and autumn.
4. **Control machinery and people movement into and out of lupin crops.** Spores of the anthracnose fungus can be transported by machinery, animals and human movement. Spores that develop during the growing season on infected plants can spread the disease within crops and between crops. *Be aware of machinery movement into and out of lupin crops, particularly contractors, as well as human activity which may spread spores between crops.*
5. **Apply a foliar fungicide at 6–8 weeks post emergence (with a grass herbicide) using fungicides containing mancozeb, chlorothalonil or azoxystrobin, and a follow up at pre-canopy closure.** Research conducted in Western Australia found that follow up foliar fungicide applications in combination with seed applied fungicides were highly effective in reducing the transmission of anthracnose between seasons.

Restrictions remain in place on the movement of lupin material and machinery into NSW from SA and WA. [32]

Chemical control

To reduce the transmission of seed borne anthracnose seed should be treated with thiram seed dressing at the rate of 100 g active ingredient per 100 kg of seed. Thiram is not compatible with rhizobium inoculums.

Dithane® Rainshield Neo Tec Fungicide, Manzate® DF and Penncozeb®750 DF are registered for controlling Anthracnose in lupin in NSW. [33]

Mancozeb label states application via spray when leaves, flowers or pods show first signs of infection and weather conditions are likely to remain humid or wet. If disease pressure is severe and conditions favour spread, repeat sprays at 2–3 weeks.

Chlorothalonil is not registered for anthracnose in lupins but can be used under permit number 82209. Do not apply more than two foliar applications per season with a re-treatment interval of 14 days.

Azoxystrobin is not registered for anthracnose in lupins but can be used under permit number 82226. Apply up to two foliar applications per season. The first application must be applied before the disease is established and no later than the onset of flowering. A second application can be made 10–14 days after the first application.

The GRDC Foliar diseases Ute Guide provides disease descriptions and images relevant to each crop.

MORE INFORMATION

Lupin Anthracnose reporting sheet

Lupin Anthracnose sample submission form

Monitoring

Growers are encouraged to inspect lupin crops regularly and report any unusual disease symptoms to their nearest NSW DPI or Local Land Services (LLS) office. Early detection will prevent establishment of the disease in NSW and protect the lupins industry. [34]

9.7 Brown leaf spot

Brown leaf spot (BLS) (*Pleiochaeta setosa*) is one of the most widespread diseases of lupin in Australia. The disease can infect lupins at all stages of growth but seedling infection has the greatest impact on yield. Spores produced on dead tissue become incorporated into the surface layers of the soil where they can persist for several years, although under non-host crops the concentration reduces over time. Infection

32 K Lindebeck, K Moore, M Richards, G O'Connor (2017) GRDC Update Papers: The Watch outs for pulse diseases in 2017. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/The-watch-outs-for-pulse-diseases-in-2017

33 G Brooke, C McMaster (2016) Weed control in Winter crops 2016. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops

34 K Lindebeck, K Moore, M Richards, G O'Connor (2017) GRDC Update Papers: The Watch outs for pulse diseases in 2017. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/The-watch-outs-for-pulse-diseases-in-2017

occurs when spores are splashed by rain from the soil onto new lupin plants. Factors which reduce the growth rate of plants such as colder environments, late sowing, poor nutrition, herbicide damage or unfavourable soil type, prolong exposure to rain-splash at the most susceptible seedling stage. The disease is more likely to occur in crops that are sown into a paddock with a bare surface and in paddocks with a recent lupin history. This is because *Pleiochaeta* spores survive in the soil.

Brown leaf spot was widespread in NSW in 2016 due to favourable winter conditions. [35]

Good crop management can prevent losses from BLS. Crop rotation, with at least a 4-year break between lupin crops and separation from last year's lupin paddock is essential for effective control. [36]

9.7.1 Varietal resistance or tolerance

Albus lupin is less affected by Brown leaf spot where it is not usually a significant problem – some lesions might develop on pods but do not cause any yield loss. All albus lupin varieties grown in NSW are rated as resistant to BLS.

Jenabillup⚈ and Jindalee⚈ have the highest disease rating at moderately resistant, while all other narrow-leafed lupins are rated moderately susceptible (see, Table 1). [37]

9.7.2 Damage caused by Brown leaf spot

Brown leaf spot is prevalent in all areas where lupins are grown. Lupin plants may be infected at any stage of growth. BLS is most important from emergence until rapid growth starts in early spring. Later, as lupins approach maturity and are growing rapidly, loss of some lower leaves due to the disease is less damaging. Infected plants that survive generally have reduced vigour, leaf area and yield. [38]

9.7.3 Symptoms

Infected cotyledons develop dark brown spots and rapidly become yellow and drop off. Leaves also develop dark brown spots, often net-like in appearance and can be distorted and reduced in size before prematurely dropping off (Photo 10). On stems, brown flecks may be evident, occasionally developing into large brown-black cankers which kill the stem above the infection point. Seedlings can rapidly become defoliated and die (Photo 11). Pods, particularly those set closer to the ground, may be flecked or develop larger brown lesions (Photo 12). Stem and pod infection are usually associated with leaf infection in the upper canopy.

35 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

36 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

37 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

38 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

Photo 10: *Brown leaf spot in narrow-leafed lupin.*

Photo: Raymond Cowley, Source: NSW DPI

Photo 11: *Severe brown spot symptoms causing stunting of seedlings with associated defoliation and distortion of cotyledons and leaves.*

Source: DAFWA

Photo 12: *Brown spot infected pods and stems.*

Source: DAFWA

9.7.4 Conditions favouring development

The disease is favoured by cool, wet conditions during seedling emergence when soil-borne spores are splashed onto leaves and cause infection.

Disease cycle

During the growing season large numbers of spores are produced when diseased leaves fall onto the soil surface. These spores start new infections when they are splashed onto foliage by rain.

The pathogen is carried over from one season to the next on previously infected plant material, in infested seed or as spores on the soil surface. At the start of the next cropping season, spores that survived the summer may become incorporated into the soil with tillage or sowing operations.

When the next lupin crop is sown, soil-borne spores germinate and infect the roots of lupin seedlings. Spores that have survived on the soil surface are splashed upwards by rain droplets, and infect leaves and stem.

Seed-borne infections are important for dissemination of the pathogen over long distances, and are responsible for initial infection in clean paddocks that are isolated from other lupin crops. Severely affected pods can contaminate seed lots and act as a source of infection after sowing. Once infection is established within the crop, secondary infection of other plant parts can occur by splash dispersal of fungal spores during rain. [39]

9.7.5 Management of Brown leaf spot

Brown leaf spot and root rot can be effectively controlled when an integrated approach to disease management is implemented. Preventive measures are necessary to protect crops in high disease risk situations, particularly in areas with intensive lupin production. This involves using a number of strategies including crop

39 H Richardson, M Haynes (2013) Brown leaf spot and Root rot of Lupins. Agriculture Victoria. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/brown-leaf-spot-and-root-rot-of-lupins

rotations, seed dressings, resistant cultivars, minimum tillage and retaining cereal stubble. There are no foliar fungicides currently registered to manage the disease. [40]

Crop rotation is an important management strategy as the number of *Pleiochaeta* spores in the soil is reduced by half, every year a non-lupin crop or pasture is grown in the rotation. The only other known host for brown leaf spot is seradella, a low-yielding legume. Sowing lupins into cereal stubble will reduce rain splash of spores onto lupin plants. Long rotations are important so that lupin stubble will be decomposed before the next lupin crop is sown.

Another important method for controlling brown leaf spot is to apply a seed dressing, although this only suppresses the disease and does not provide complete control. Registered seed treatments containing either iprodione or procymidone will reduce the transfer of the disease to the seedling, and can reduce leaf drop by 50%.

Variety selection is also an important management strategy. New narrow leaf lupin varieties have been released with resistance to brown leaf spot. Small differences in brown spot tolerance exist between narrow-leafed lupin varieties but this does not remove requirement for other management approaches. Broad leaf lupin varieties are available with tolerance to brown leaf spot, but can be susceptible to root rots under wet conditions, and so are limited to well-drained soils. [41]

Factors which promote seedling vigour and canopy closure such as early sowing, adequate nutrition, care in herbicide use, higher seeding rates and sowing onto favourable soils reduce disease impact. [42]

The GRDC Foliar diseases Ute Guide provides disease descriptions and images relevant to each crop.

9.8 Phomopsis

Phomopsis stem and pod blight (*Diaporthe toxica*) occasionally causes yield losses, however the major impact of infection is the production of a mycotoxin (phomopsin) by the fungus as it grows in mature lupin stems or in seed. The toxin can cause sickness or death (lupinosis) in livestock if grazing of infected stubble is poorly managed. Spores released in winter from fruiting bodies on stubble infect growing lupin plants but rarely cause lesions at this stage unless plants are stressed by drought, herbicide or frost. The infection remains latent as microscopic structures until senescence of the plant tissue. Moisture, such as summer rain, on the mature infected tissue allows the fungus to grow saprophytically producing the mycotoxin and also new fruiting bodies.

In 2015 and 2016, outbreaks of the disease were mainly found on albus lupin varieties, particularly Rosetta⚲, in southern NSW. Phomopsis was detected again in late spring 2016 in NSW due to a combination of wet winter conditions and moisture stress in late spring (which can trigger the disease in green plants) as crops were maturing.

Current breeding is directed towards producing resistant types. Until recently, this disease was known to occur only in narrow-leafed lupin. Symptoms usually become obvious only at maturity or after harvest. Infected seed is discoloured and may have mould growth. The fungus has a major impact on germination percentage.

Infected stubble can be highly toxic to livestock, causing lupinosis, particularly if it is grazed under very humid or wet conditions following rain. Phomopsis levels can increase in stubble of all lupin varieties – whether resistant or susceptible – following rain after harvest. [43]

40 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

41 H Richardson, M Haynes (2013) Brown leaf spot and Root rot of Lupins. Agriculture Victoria. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/brown-leaf-spot-and-root-rot-of-lupins

42 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

43 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

9.8.1 Varietal resistance or tolerance

Current albus lupin varieties have a good level of resistance to stem infection by the phomopsis pathogen, but are susceptible to pod and seed infection especially after heavy rain, wind, or hail close to harvest (Photo 13). Jindalee⦻, Mandelup⦻, PBA Gunyidi⦻, PBA Jurien⦻ and Wonga⦻ are rated resistant to Phomopsis (see, Table 1). Current narrow-leaf lupin varieties vary in their resistance rating for phomopsis. If lupin stubble grazing is required, it is recommended to grow a variety with the R rating for phomopsis.

Photo 13: *Comparison of albus lupin variety resistant to Phomopsis (right) and the susceptible breeding line WK264 (left). Note the darkened and shrivelled pods.*

Photo: Raymond Cowley, Source: NSW DPI

9.8.2 Damage caused by Phomopsis

Phomopsis infection of the stems and pods can cause stem collapse and reduce yield if there is a water deficit at the end of the season. The fungus has a major impact on germination percentage (Figure 1). [44]

44 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

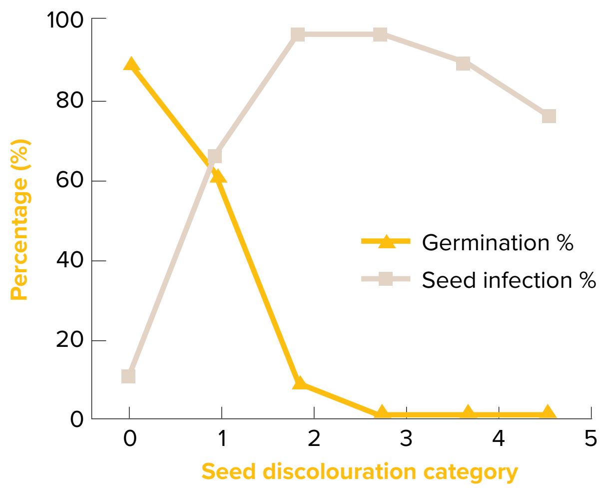

Figure 1: *Effect of Phomopsis seed infection on germination, and levels of seed-borne Phomopsis in a heavily infected sample of Kiev Mutant. The seed was sorted into the seed discolouration categories shown in Figure 4–15.*

Source: Cowley et al. (2010) in NSW DPI

Be aware of the potential danger to stock grazing stubble, and seed infected with the phomopsis stem blight fungus. Look for pink, tan or brown discoloured or mouldy seed. Do not feed grain to stock or deliver for human consumption if phomopsis-infected seed is suspected.

9.8.3 Symptoms

Symptoms usually appear on senescing or dry lupin stems as dark purplish brown lesions which bleach with age and contain black fruiting bodies (Photo 14). Lesions can develop on pods, causing the surface of green pods to become 'slimy' and mature pods to be shrivelled with dark discolouration (Photo 15). Pod lesions can lead to seed infection, causing shrivelled seed or whole seeds with golden brown discolouration (Photos 16 and 17). Infected seed may also contain mycotoxin.

Photo 14: *Characteristic pycnidia ('leopard spotting') of Phomopsis on albus stubble. Stems such as these contain the toxins responsible for lupinosis.*

Photo: Raymond Cowley, Source: NSW DPI

Photo 15: *Albus lupin pods infected with Phomopsis (top) and brown leaf spot.*

Photo: Raymond Cowley, Source: NSW DPI

Photo 16: *Pods and seeds heavily infected with Phomopsis. Within an infected pod there can be differences in the level of disease on each seed.*

Photo: Raymond Cowley, Source: NSW DPI

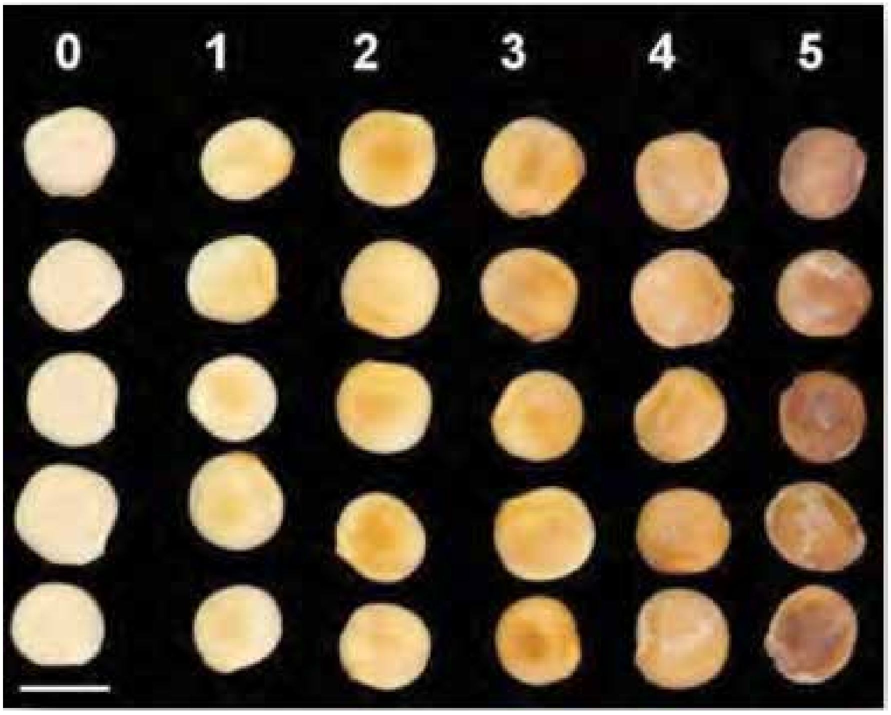

Photo 17: *A 0–5 seed infection (discolouration) scale used to determine the severity of Phomopsis infection of a seed lot.*

Photo: Raymond Cowley, Source: NSW DPI

9.8.4 Conditions favouring development

There are two sources of infection in lupin crops; spores dispersed from neighbouring crops or stubbles and/or pathogen spread by sowing infected seed.

Phomopsis of lupin stubble can occur after summer rainfall, leading to toxin production on stubble. Spores are released in winter from fruiting bodies. The disease can also develop on green lupin plants, in some conditions. Stresses such as drought, herbicide injury or frost may trigger the growth of the phomopsis pathogen in green plants and the production of toxins, which can affect livestock.

The fungus may spread rapidly through the crop if there is high humidity around the time of harvest maturity. Although the fungus is capable of penetrating undamaged pods and stem tissue, anything causing wounding can result in rapid fungal spread and development in a crop. Wounding can be caused by insects or hail. If pod infection occurs late as a result of wounding, more infected seed will be harvested. [45]

Time of harvest and un-harvested

Lupins Delayed harvest may increase phomopsis infection if weather conditions are suitable. In years with dry summers lupins that are not harvested can generally be grazed safely, provided they have been inspected for signs of infection. In wet summers however, the risk of lupinosis occurring is greater. [46]

9.8.5 Management of Phomopsis

Variety resistance is the most effective way of reducing phomopsis. All current narrow leafed lupin varieties have moderate levels of resistance to stem and pod infection, although stem and pod resistance can be independent and may difffer within individual varieties. Since 1988 new narrow-leaf lupin varieties have been bred with improved levels of resistance. Resistant varieties have much less phomopsis stem blight on mature, dry stems compared to susceptible varieties. The risk of lupinosis is reduced when resistant varieties are grown.

Sowing of seed free of this disease is currently one of the only method available to growers to minimise potential yield losses. Inspect seed to be used for sowing prior to sowing the crop. If infected seed is sown the risk of phomopsis establishing within the crop increases, heightening the risk of lupinosis. Infected seed weighs less than normal seed and may be graded off using an air-table. Seed-borne phomopsis will reduce germination in both narrow-leaf and broad-leaf lupins. Heavily infected seed does not germinate (Photo 18). Only clean or lightly infected seed germinates well. Avoid sowing infected seed.

45 R Crowley, G Casburn (2013) PrimeFact: Reducing the risk of lupinosis and the incidence of phomopsis. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/478243/Reducing-the-risk-of-lupinosis-and-the-incidence-of-phomopsis.pdf

46 R Crowley, G Casburn (2013) PrimeFact: Reducing the risk of lupinosis and the incidence of phomopsis. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/478243/Reducing-the-risk-of-lupinosis-and-the-incidence-of-phomopsis.pdf

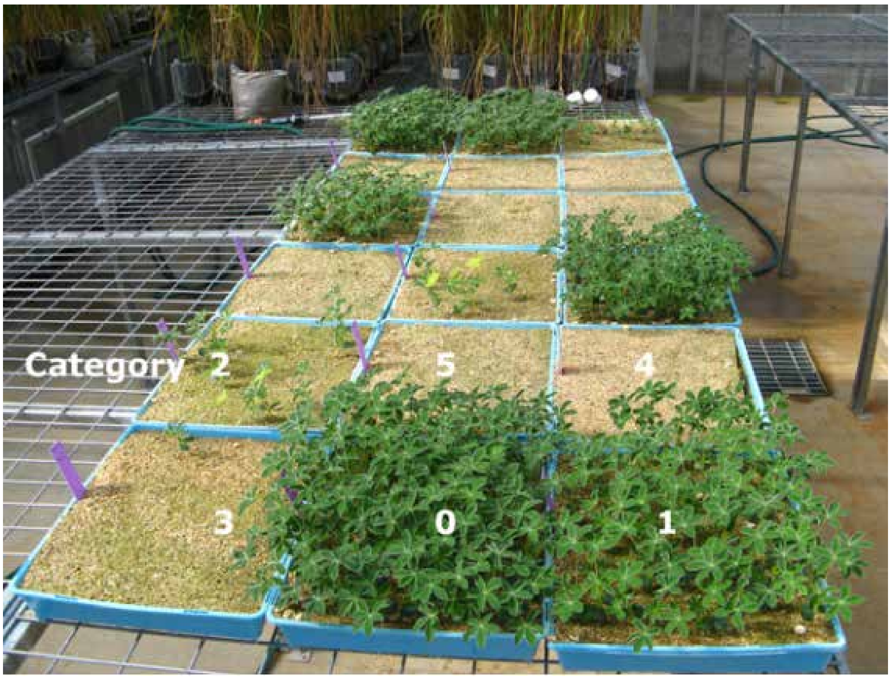

Photo 18: *The effect of phomopsis infection on germination. Only seed from categories 0 and 1 germinated.*

Source: NSW DPI

Increasing breaks between lupin crops allows weathering and breakdown of infected stubble, reducing disease inoculum.

Ensure to harvest on time as delayed harvest can increase the risk of phomopsis. [47]

Stubble management

Practices that encourage rapid breakdown of infected stubble will reduce the potential risk of lupinosis. Infected stubble can be burnt or incorporated into the soil to aid rapid breakdown, but only if there is a lupin crop nearby or has been planted in the same paddock in the previous four years. In no-till situations, inspect stubble for pycnidia development before grazing is allowed. In seasons with summer rain, stubble must be inspected frequently. If weather conditions favour the pathogen (prolonged rainfall or high humidity in late spring and summer), stubble may still develop some toxicity requiring care with grazing, however usually current varieties do not produce highly toxic stubbles.

Strategies to avoid lupinosis in stock involve careful grazing management in the first few months after harvest and growing a narrow-leaf lupin variety with the best available phomopsis resistance. Manage the disease through separating this year's crop from last year's paddock and avoid growing lupin for at least four years in the same paddock. [48]

The GRDC Foliar diseases Ute Guide provides disease descriptions and images relevant to each crop.

9.8.6 Grazing lupin stubble to minimise Phomopsis

Lupin stubbles can be a high value feed source for livestock, however growers have lost stock to lupinosis. This livestock health problem occurs as a result of toxins being produced from the phomopsis fungus that develops in the lupin stem as the plant matures. All current varieties have a reasonable level of resistance that slows the

47 R Crowley, G Casburn (2013) PrimeFact: Reducing the risk of lupinosis and the incidence of phomopsis. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/478243/Reducing-the-risk-of-lupinosis-and-the-incidence-of-phomopsis.pdf

48 R Crowley, G Casburn (2013) PrimeFact: Reducing the risk of lupinosis and the incidence of phomopsis. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/478243/Reducing-the-risk-of-lupinosis-and-the-incidence-of-phomopsis.pdf

development of the phomopsis fungus. However, when significant rains occur while the crop matures and afterwards, fungal development can still occur, regardless of the resistance level of the plant. Care must be taken in grazing lupin stubbles and it may be advisable not to graze some paddocks at all should wet conditions prevail at or after harvest. Lupin paddocks should be grazed at the first opportunity after harvest and stock should have access to a good quality water supply. Older animals are less affected by lupinosis than young animals. Producers should note; bulky crops, crop topping and tight lupin crop rotations aid the development of the fungus and can increase the risk of lupinosis occurring. [49]

Mixed farmers who are planning to graze animals on lupin stubbles are encouraged to check the stubble carefully for signs of phomopsis to avoid the onset of lupinosis.

MORE INFORMATION

Reducing the risk of lupinosis and the incidence of phomopsis

Samples of albus lupin were received at the Wagga Wagga Agricultural Institute in late October 2015 with symptoms of phomopsis stem blight. Symptoms on the main stem can look similar to what would normally be associated with sclerotinia; large, oval-shaped and bleached lesions. The difference, however, is small, raised, black fruiting structures within the lesions, characteristic of what appears on lupin stubble following summer rain and typical of phomopsis. These suspect plants had also lodged (collapsed) at the point of the lesion.

Growers who suspect that phomopsis may have infected their lupin stubbles are encouraged to have the symptoms confirmed by their local agronomist. [50]

9.9 Sclerotinia stem rot

Sclerotinia stem rot (*Sclerotinia sclerotiorum*) is a fungal disease which infects most broad leaf crop and pasture species but not cereals.

Sclerotinia infection of the stem can cause stem collapse. If infection occurs at the stem base, the plant can die. This disease can infect a wide range of broad-leafed plants, so using appropriate rotations is currently the best means of control. The disease can occur in both albus lupin and narrow-leafed lupin. [51]

It is most common in higher rainfall areas and usually affects plants after flowering in warm and damp conditions. Outbreaks of the disease are sporadic dependent on paddock history and seasonal weather conditions, often the disease affects only a percentage of the crop and the loss of yield is proportional to area infected. Crops with lush dense canopies in seasons with regular rainfall are at greatest risk, particularly when sown on paddocks with a history of sclerotinia infection in canola or lupins previously. In severe cases sclerotia become mixed with harvested seed which may incur extra cost of grading seed to remove them.

This disease is caused by the same fungus that infects canola. Districts with reliable spring rainfall and long flowering periods for lupin appear to develop the disease more frequently. Outbreaks of the disease were reported in southern and central NSW in 2016, driven by above average rainfall and wet crop canopies. Be aware of crop rotations that include lupin and canola in close rotation as this can increase soil-borne sclerotia. Burning canola or lupin stubble will not effectively control Sclerotinia as sclerotia survive mainly on, or in, the soil. Crop rotation with cereals, following recommended sowing times and ensuring crops do not develop heavy vegetative growth, which are likely to reduce air circulation, are the best means of managing the disease. There are currently no foliar fungicides registered to manage Sclerotinia of lupin. [52]

49 SARDI (2017) 2017 Sowing guide – South Australia. GRDC. https://grdc.com.au/SA-SowingGuide2017

50 N Baxter (2016) Lupinosis warning. GRDC. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-120-Jan-Feb-2016/Lupinosis-warning

51 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

52 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

9.9.1 Varietal resistance or tolerance

There is no data available for lupin variety resistance to Sclerotinia.

9.9.2 Symptoms

Predominantly lesions occur in the upper half of the main stem or branches and on flowers and pods. The fungus produces a white cottony-looking growth that girdles the stem, causing the plant parts above the lesion to wilt and die. Infected pods can be completely covered by this white fungal growth. Hard black sclerotia, 2–8 millimetres (mm) in diameter, are produced in the fungal growth or in the cavities of infected stems or pods (Photos 19 and 20). Sclerotia can survive in soil for several years and are the source of new infections. [53]

Photo 19: *Sclerotinia affected lupin pods with black sclerotes obvious on the outside of pods.*

Source: DAFWA

53 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

Photo 20: *Inside the pods, seed can be infected.*

Source: DAFWA

9.9.3 Conditions favouring development

The environmental conditions for Sclerotinia to develop are very specific and will not occur every year, so even when the fungus is present the disease could fail to develop in dry conditions. Disease development is favoured by prolonged wet conditions in late winter followed by periods of prolonged leaf wetness during flowering. [54]

9.9.4 Management of Sclerotinia

Key points:

- Crop rotation can have some effect, although sclerotia survive for significant periods. Cereals are non-hosts and provide the most effective disease break.
- Avoid sowing lupins in close rotation with other broad leaf crop species such as canola.
- Foliar fungicides are not currently registered for sclerotinia in lupins.

No fungicides are currently registered for management of sclerotinia in lupin, permit applications for new products are in place but very little is known about potential timing of fungicide application and any impact that may occur. [55]

The GRDC Foliar diseases Ute Guide provides disease descriptions and images relevant to each crop.

9.10 Botrytis grey mould

Botrytis grey mould is a foliar disease caused by the fungal pathogens *Botrytis cinerea* and *Botrytis fabae*. The fungi are serious, but sporadic disease of pulses in Australia. The disease is capable of causing serious yield losses, particularly in dense, early-sown crops, when spring rainfall is high and there are prolonged wet periods. An integrated approach to managing Botrytis will minimise yield losses.

54 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

55 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

9.10.1 Symptoms

The disease can infect all above ground parts of the plant, including leaves, stems and pods. The first symptoms are greyish-brown lesions on the lower leaves of the plant. However, no black fruiting bodies are produced within the lesions.

Infected leaves can become covered with a fuzzy layer of grey mould near the base of the plant. The stem lesions will appear light brown or bleached and can be covered in grey, mouldy growth (Photo 21). The mouldy growth consists of spore masses that can quickly spread to infect surrounding plants. Clouds of spores can rise from infected plants if they are disturbed. Dark black fungal bodies, known as sclerotia, can develop on stems and it is these structures that survive over summer on stubble. Severely infected leaves, flowers and pods wilt and fall to the ground. Plants ripen prematurely due to infection of the lower stem. If conditions remain wet throughout spring, stems can become girdled and patches of brown dying plants appear in the crop. Infected pods will fail to fill properly and will produce shrivelled seed or no seed at all. Infected seed is discoloured.

Photo 21: *Large sunken lesions can girdle stems and branches and kill lupin plants. Mature lesions have grey fuzzy mould.*

Source: DAFWA

9.10.2 Conditions favouring development

The disease inoculum readily survives on alternate hosts such as faba bean and chickpea, which are also grown in close rotation with lupin. The pathogens can survive on stubble residue or in the soil as sclerotia but can also be carried on infected seed. When seed infected by these fungi are sown seedling blight will occur soon after crop emergence, reducing plant populations. Masses of spores are produced on infected plants which can then spread onto surrounding plants by wind and rainsplash to begin new infections.

Symptoms of grey mould appear more commonly in early spring. Dense crop canopies combined with warm, wet conditions in late winter and early spring favour development and spread of the disease. Moisture is essential for infection. Pulse crops sown early and/or at high seeding rates appear to be the worst affected by BGM. The disease usually starts off affecting the base of the stem. Prolonged wet conditions can cause it to progress higher up the plant subsequently affecting pods.

MORE INFORMATION

Seed Health Testing in Pulse Crops (AG1250)

9.10.3 Management of Botrytis

As with many diseases, the best management strategy is to sow crops with greater resistance to the disease.

Use Clean Seed

Only use seed with less than 5% botrytis infection; ideally use seed with nil infection. Using old or damaged seed can reduce seedling vigour and increase susceptibility to infection.

Paddock Selection

Avoid planting this season's crop near old stubble of susceptible crops. These crop residues can harbour *Botrytis species.* A program of stubble reduction may also be undertaken by grazing or burying to reduce the carry- over of infected stubble into the following season. Allow a break of at least 3 years between susceptible crops.

Seed Treatment

Use a registered seed treatment for the control of seed-borne diseases in lupin. Seed treatments can have a deleterious effect on rhizobia. Therefore, seed should be treated with fungicide and then inoculated with rhizobia in two separate operations. Rhizobia should be applied to seed immediately before sowing, especially on acid soils.

Sowing

Sow later and reduce seeding rates. Early sowing and high sowing rates can cause rank crop growth, lodging and increased risk of grey mould. Follow the recommended sowing rates and sowing dates for your district.

Use Foliar Fungicides

In areas of high risk it may be necessary to apply foliar fungicides to protect the crop, especially if a susceptible variety is being grown. Fungicides should be applied before canopy closure for best results. If conducive (warm and wet) conditions continue, follow up sprays may be necessary 12- 14 days later.

There are a range of fungicides available to control botrytis and selection of the most appropriate fungicide could depend on the level of disease pressure present. Fungicides containing mancozeb, chlorothalonil, carbendazim, or procymidone have activity against botrytis (see, Table 2). If disease pressure is high then carbendazim or procymidone are the preferred fungicides. It is worth noting that these products are protectants and are most effective if applied before disease development. [56]

56 CropPro (2014) Botrytis Grey Mould of Lentil. http://www.croppro.com.au/crop_disease_manual/ch08s03.php

9.11 Chemical control of fungal disease

Consider the variety grown, potential crop yield, rainfall zone and disease risk when deciding on fungicide use.

Seed Treatment

Seed treatments are a cheap and effective method for suppressing some diseases. Treating pulse seed with a fungicide reduces the establishment of seed-borne diseases in crops and also protects seed from infection by soil-borne fungi. Some fungicide seed dressings also protect seedlings from external airborne infection for the first few weeks. This is important in reducing the subsequent establishment and spread of disease within crops. Seed treatments provide effective control for a maximum of four to six weeks after sowing, but do not provide absolute control.

Application

It is important for seed treatments to be evenly distributed on seed to ensure each seed gets an effective dose. This is enhanced for flowable seed treatments by dilution with water (refer to the label). Secondary mixing of treated seed through an auger assists to obtain even seed coverage. Correct calibration of the applicator and a consistent seed flow are critical for the recommended rate of seed treatment to be applied.

Applying fungicides and rhizobium inoculant to seed

Some fungicides are toxic to rhizobium, and should not be mixed together before application to seed. Read the labels for compatibilities. Ideally, seed should be treated with fungicide and then, in a separate operation, inoculated with rhizobium just before sowing. Sowing should occur immediately after rhizobium has been applied, particularly in acid soils. Granular or liquid injection of inoculum infurrow eliminates the contact between seed treatments and rhizobia.

Foliar fungicides

Foliar fungicides are necessary for controlling some destructive pulse diseases (Table 2). They are most effective when applied before or at the first sign of disease, or immediately prior to weather conditions favourable for disease development. Do not wait until the disease is established; i.e. apply ahead of rain fronts, as pulse fungicides protect rather than cure. Fungicides provide protection for 10–20 days. The duration of protection varies with the product used, how rapidly the plants are growing, and the rainfall experienced. Any new growth after spraying is not protected. If disease persists, additional sprays will be required and should be applied prior to rain. Waiting until after a rain event allows infection to occur.

Application

Uniform coverage of the crop foliage is important for prevention of disease. This is best achieved by using high water rates (preferably 100 L/ha by ground and 30 L/ha by air) with water pH not exceeding pH7, nozzles with a fine or extra fine droplet spectrum and an operating pressure of 400 kPa is suggested. Application onto a wet plant (heavy dew) can assist in coverage of the product. [57]

57 W Hawthorne, J Davidson, K Lindbeck (2011) Australian Pulse Bulletin – Pulse seed streatments and foliar fungicides. Pulse Australia. http://pulseaus.com.au/storage/app/media/crops/2011_APB-Pulse-seed-treatments-foliar-fungicides.pdf

Table 2: *Pulse foliar fungicides – 2016 Foliar fungicides for lupin, canola, chickpea, field pea and faba bean.*

Example foliar fugicide trade name and manufacturer	Active ingredient	Harvest withholding period (WHP) – weeks/days		Rate to apply per hectare (L/ha or kg/ha)	Cost of product per litre ($)	Size of pack (kg or L – range of pack sizes)
		Harvest	Grazing			
Bravo® Weather Stik – Syngenta	chlorothalonil (720 g/L)	7 days	Do not graze	1.4–2.3 L	13.20	10–100 L 5–200 L
Barrack® Betterstick – Crop Care	chlorothalonil (720 g/L)	7 days	Do not graze	1.4–2.3 L (Faba beans) 1.0–2.0 L (Chickpeas)	13.20	10–100 L 5–200 L
Barrack® 720 – Crop Care Unite® 720 – Nufarm	chlorothalonil (720 g/L)	14 days	14 days	1.4–2.3 L (Faba beans) 1.0–2.0 L (Chickpeas)	13.20	5–200 L 5–1000 L
Echo® 900 Fungicide – Sipcam	chlorothalonil (720 g/L)	14 days	14 days	1.2–1.9 L (Faba beans) 0.8–1.6 L (Chickpeas)	17.55	1–20 kg
Rovral® Liquid – FMC Iprodione Liquid 250 – Cheminova	iprodione (250 g/L)	42 days	42 days	2.0 L	18.30	54–1000 l
Dithane® Rainshield Neo Tec Fungicide – Dow AgroSciences	mancozeb (750 g/kg)	28 days	14 days	1.0–2.2 kg	9.50	20 kg
Manzate® DF – Sipcam	mancozeb (750 g/kg)	28 days	14 days	1.0–2.2 kg	9.50	10–20 kg
Penncozeb® 750 DF – Nufarm	mancozeb (750 g/kg)	28 days	14 days	1.0–2.2 kg	10.45	10 & 20 kg
Polyram® DF – Nufarm	metiram (700 g/kg)	6 weeks	21 days	1.0–2.2 kg	13.20	15 kg
Fortress® 500 – Crop Care Sumisclex® Broadacre –Sumitomo	procymidone (500 g/L)	Canola not required Faba beans 9 days	9 weeks Not stated	1.0 L (canola) 0.5 L (faba beans)	49.55	5–10 L 20 L
Prosaro® 420 SC –Bayer CropScience	prothioconazole (210 g/L) + tebuconazole (210 g/L)	Not required	14 days	375–450 ml/ha	77.00	5–20 L
Folicur® 430 SC – Bayer CropScience Hornet® – Nufarm Triadimefon 125EC – Cheminova	tebuconazole (430 g/L)	3 days PER13752 21 days	3 days PER13752 14 days	145 ml	13.20	Folicur 5–60 L Hornet 20 L
Triadimefon 125EC – Cheminova	triadimefon (125 g/L)	14 days	Not stated	500 ml	6.00	5–1000 L

Source: NSW DPI

Registration status: The product must be registered or have a permit for the disease and use.

Withholding period: All products and timings used in the fungicide program must meet Australian withholding periods and export slaughter intervals.

Fungicide resistance management: Adhere to the maximum number of sprays of a product to minimise the risk of fungicide resistance developing.

Mode of action: To further reduce the chance of fungicide resistance development and to improve efficacy, use products with a range of mode of actions. Fungicides are also recommended at times of the disease life cycle where they will be most effective according to their mode of action. [58]

9.12 Cucumber mosaic virus

Cucumber mosaic virus (CMV) is a seed and aphid-borne virus that infects lupins. Historically, high rainfall zones have had highest disease risk.

CMV is a sporadic problem in southern NSW. This disease tends to be more prevalent in central and northern NSW, but only in narrow-leaf lupin. Albus lupin is immune to the disease. It can also be seed borne. The prevalence of CMV in northern NSW is one reason why albus lupin, rather than narrow-leafed lupin, is grown in that region. [59]

The virus is spread from plant to plant by aphids (Photo 22). Infected plants will be stunted and bunchy and have few pods. They remain green while other plants are haying off.

Photo 22: *Bluegreen aphid on flowering bud of a lupin plant.*

Source: DAFWA

9.12.1 Varietal resistance or tolerance

Wonga⨀ is the most resistant narrow-leaf lupin to CMV seed transmission (see Table 1). All albus lupin varieties are immune to CMV.

58 Pulse Australia (2015) Australian Pulse Bulletin: Chickpea integrated disease management. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies

59 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

9.12.2 Damage caused by Cucumber Mosaic Virus

CMV can cause symptoms in all narrow-leaf lupin varieties, but it is the seed transmission from infected plants that causes problems for growers. The infected seed then carries over the disease into next year's lupin crop. Infected plants are most commonly seen around crop margins and in areas of low plant density or in gaps.

Yield losses can reach 60% when all plants in a crop become infected. Yield reductions of 10 to 40% are common in infected crops. Losses from CMV infection are greatest when seed with >1% infection is sown, aphids arrive early and widespread plant infection occurs. However it is important to note that seed infections at less than 0.5% can still result in serious crop infections and yield loss. [60]

9.12.3 Symptoms

Plants grown from infected seed are stunted with pale, bunched, down-curled, faintly mottled leaves (Photo 23). Plants infected by aphids during the season exhibit similar symptoms on plant parts that emerge following infection, older leaves present before infection remain healthy (Photo 24). Pod set and seed size are both reduced in infected plants. [61]

Photo 23: *Current season infection with cucumber mosaic virus in narrow-leafed lupin. Lower leaves are normal looking, while leaves at the growing tip are pale, bunched and down curled.*

Source: GRDC, Photo: E Collis

60 B Coutts (2017) Cucumber mosaic virus in narrow-leafed lupins. DAFWA. https://www.agric.wa.gov.au/grains-research-development/cucumber-mosaic-virus-narrow-leafed-lupins?page=0%2C1

61 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

Photo 24: *Infection showing CMV symptoms in plant parts emerged following infection (left). Seed borne infection with CMV symptoms evident in whole plant (right).*

Source: DAFWA

9.12.4 Conditions favouring development

Rainfall in summer and autumn has a major effect on virus infections in crops. High rainfall during this period leads to a build up of weed hosts for viruses and the growth of self sown pulses. Aphids are also favoured by a wet summer and autumn. Aphid population development is strongly influenced by local conditions. Early breaks and summer rainfall favour early increases in aphids and volunteers that host viruses, resulting in a higher level of virus risk.These conditions can lead to an early infection which can then have a major impact on growth and yield. [62]

9.12.5 Management of Cucumber Mosaic Virus

Key points:

- Narrow-leaf lupin seed should be tested for CMV infection.
- Best management practices, including retaining standing cereal stubble and weed control (to deter aphids), will reduce disease incidence.
- Integrated management practices that aim to control aphid populations early in the season are important to minimising virus spread.

An integrated disease management approach is needed to control CMV in lupin crops, one which uses a range of control measures.

Sowing healthy lupin seed. This is the most important measure. A representative seed sample is tested to determine the level of infection. In low risk areas, seed with <0.5% infection can be sown without undue risk of yield loss. Seed infection of <0.1% (a zero result from a 1000 seed test) is recommended for grain crops in high risk areas, and for seed certification crops in any rainfall zone. The NSW DPI plant pathology team at Tamworth offer a free seed testing service as part of a GRDC funded Integrated Disease Management project.

It is important to observe the conditions and consider avoiding susceptible crops if the risk of viral infection is potentially high. If the season is considered high risk it is important to control weeds and self sown crops early, and certainly before they can support a population of aphids. This will be well prior to sowing pulses.

62 GRDC (2010) Aphids and viruses in pulse crops – Fact sheet. https://grdc.com.au/__data/assets/pdf_file/0019/205642/aphidsvirusesfactsheets.pdf.pdf

MORE INFORMATION

Cucumber mosaic virus in narrow-leafed lupins

Cucumber mosaic virus of lupins

Aphids and viruses in pulse crops.

Managing viruses in pulse crops

Managing Viruses in Pulses

Varieties differ in their rate of seed transmission of this disease. Varieties with low seed transmission rates are recommended for high rainfall environments. Albus lupins are not hosts of CMV.

Sow early at high seeding rates using narrow row spacing to promote early crop canopy coverage. This deters aphids from landing and shades over the seed-infected and early infected plants, denying aphids access to them.

Direct drill into retained stubble. Ground cover reduces aphid landing rates before a crop canopy develops, especially with wide row spacing.

Minimise the pool of potentially virus-infected plant material near crops by controlling the green bridge of weeds, pastures and volunteer pulses that can harbour viruses and aphids over summer or between crops. This includes weeds around dams, tracks and the margins of crops. Isolate from neighbouring lupin crops.

Some species of aphids are attracted to areas of bare earth. Use minimal tillage and sow into retained stubble, ideally inter-row to discourage aphid landings. This applies especially to minimising CMV spread in lupins. [63]

Controlling aphids

Monitor crops and neighbouring areas regularly. Identify the species of aphid present and their numbers.

Beneficial insects – including hover flies, lacewings, ladybirds and parasitic wasps – will attack aphids and assist in preventing aphid levels from increasing. Beneficial insects can help reduce virus spread and spring feeding damage, but some virus spread will have occurred before aphid numbers subside. The risk of non-persistently transmitted viruses can be reduced by an integrated disease management approach applied prior to seeding that includes a range of crop hygiene and management measures.

Seed treatment is an option for districts where aphid pressure is high in most seasons. Insecticide applied as seed dressings will help control aphid attack and the spread of viruses. Seed dressings help to protect the crop from aphids and virus transmission right from early establishment. The use of insecticide seed treatments can delay aphid colonisation and reduce early infestation and aphid feeding. Both persistently and non-persistently transmitted viruses can be controlled with seed dressings. The widespread use of neonicotinoid seed dressings does pose some risks to the build-up of natural enemies (no aphids early = nothing for them to eat) and potentially insecticide resistance.

Foliar insecticides applied soon after crop emergence can help control persistently transmitted viruses, but are of little benefit against non-persistently transmitted viruses. Preferably use a 'soft' insecticide, such as pirimicarb (registered for lupins only), that targets the aphids and leaves beneficial insects unharmed. [64]

9.13 Bean yellow mosaic virus

Bean yellow mosaic virus (BYMV) causes a serious disease in narrow-leafed lupins. BYMV is found predominantly in high rainfall wheatbelt zones but occurs less often in medium rainfall zones. Bean yellow mosaic virus (BYMV) is a common virus infection in both narrow-leaf and albus lupin. The disease causes yellowing, wilting and plant death. It is most common on crop margins and near gaps in the crop where aphids land more often.

There are no seed-borne BYMV strains in Australia.

63 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

64 GRDC (2010) Aphids and viruses in pulse crops – Fact sheet. https://grdc.com.au/__data/assets/pdf_file/0019/205642/aphidsvirusesfactsheets.pdf.pdf

9.13.1 Varietal resistance and tolerance

Jenabillup⦇ has the best resistance to BYMV but is still only rated as moderately resistant. Most narrow-leaf lupin varieties are rated as moderately susceptible (see, Table 1). There is no data available for the resistance of albus lupins to BYMV.

9.13.2 Damage caused by Bean Yellow Mosaic Virus

Infection of plants with BYMV when they are young causes greater yield losses than infection that occurs when they are older. On an individual plant basis, BYMV-N causes high yield losses as it kills young plants so no seed forms on them. On the whole crop scale, BYMV-NN has greater potential to cause losses as it spreads to more plants. When all plants in a crop become infected with either type of BYMV, yield losses can reach 80%. Plants that develop black pods resulting from late season infection will not produce any seed. [65]

9.13.3 Symptoms

BYMV infection in narrow-leaf lupin can cause three types of symptoms:

- When infected before pod set, the most common symptom is necrotic that kills the infected plant (BYMV-N).
- The less common non-necrotic symptom causes stunting without killing the plant (BYMV-NN).
- There is also the less common non-necrotic symptom causes stunting without killing the plant. Plants can be infected after pod set where black pods develop (black pod syndrome).

BYMV-N

Initial symptoms are necrotic streaking of the youngest portion of the shoot, which bends over causing a characteristic 'shepherd's crook' appearance (Photo 25). The growing tip dies, and leaves become pale, wilt and fall off. Necrotic streaking and blackening then spread throughout the stem causing the plant to die. Plants infected early die quickly and do not produce seed. When old plants become infected, the necrotic symptoms are slower to spread and may be restricted to some branches or the section of the plant near to the infection site. These shoots die and their pods blacken and fail to fill while the rest of the plant grows normally.

65 B Coutts (2017) Bean yellow mosaic virus in lupins. DAFWA. https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins?page=0%2C1

Photo 25: *Bean yellow mosaic virus – early season infection causes tip death of narrow-leaf lupin.*

Source: DAFWA

BYMV-NN

Non-necrotic symptoms on younger leaves show pallor, mottling and leaf deformation and the affected plant is stunted. Sometimes, the death of growing points causes fleshy, expanded leaves to develop on the rest of the plant. Infected plants produce few seeds and endemic BYMV strains are not seed-borne.

Black pod syndrome

Infection after pod set leads to pods turning black and necrotic stem streaking (Photo 26). Leaves turn yellow and drop. Seeds will fail to develop. Varieties vary in symptom development. [66]

66 B Coutts (2017) Bean yellow mosaic virus in lupins. DAFWA. https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins?page=0%2C1

Photo 26: *Bean yellow mosaic virus – late season infection causing black pod syndrome.*

Source: DAFWA

9.13.4 Conditions favouring development

The main source of BYMV is infected clover plants in adjacent pastures. The virus is seed-borne in clover and survives from one growing season to the next in the pasture seed bank. Clover weeds in lupin crops are an additional source if not controlled. Perennial native legumes in adjacent bush may occasionally act as BYMV reservoirs.

If there are no internal clover weed sources, BYMV infection is highest near the edge of a lupin crop close to pasture, especially at its windward edge. For BYMV-N, there is only a brief period between initial symptom formation in young plants and their death, so incoming aphids can only acquire the virus from infected lupin plants for one to two weeks. Infection incidence declines rapidly with increasing distance into the crop. Plants infected with BYMV-NN remain green and attractive to aphids. They therefore provide a continuous source of infection within the crop so aphids spread it away from the crop edge at a faster rate. [67]

9.13.5 Management of Bean Yellow Mosaic Virus

The extent of BYMV spread in crops depends on many factors. The most important include:

- Time of aphid arrival. Early aphid arrival favours earlier and more extensive spread and greater yield losses.

67 B Coutts (2017) Bean yellow mosaic virus in lupins. DAFWA. https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins?page=0%2C1

- The source of the virus. As spread declines rapidly over distance, infected pastures adjacent to crops are much more important sources than infected pastures further away. If abundant clover weeds remain uncontrolled within the crop, they may result in greater spread than external sources.
- Abundance of colonising and non-colonising aphids during the growing season. This increases BYMV spread in the crop.
- Lack of groundcover; sparse stands; poor canopy development; heavy grazing of nearby pasture; paddocks with large perimeter to area ratios; and extended growing seasons. All these factors increase BYMV spread.

An integrated disease management approach is needed to control BYMV in lupin crops:

- Sow early at high seeding rates using narrow row spacing to promote early crop canopy coverage. This deters aphids from landing and shades over early infected plants, denying aphids access to them. High plant densities dilute the proportion of plants that become infected and increase compensatory growth of healthy plants.
- Direct drill into retained stubble. Groundcover reduces aphid landing rates before a crop canopy develops.
- Sow a non-host crop (for example, cereal) border strip between crops and adjacent pasture. Incoming aphids lose the virus when they probe the non-host which helps to decrease spread into the crop from an external source.
- Avoid paddocks with large perimeter to area ratios. This reduces exposure of the crop margin to adjacent BYMV-infected pasture.
- Control clover weeds effectively. This minimises potential virus infection sources within the crop.

Note: Insecticides applied to crops are ineffective at controlling BYMV. [68]

For more information, see Controlling aphids, Section 9.9.5 above.

MORE INFORMATION

Aphids and viruses in pulse crops.

Managing viruses in pulse crops

9.14 Minor seedling diseases

9.14.1 Charcoal rot

Charcoal rot (*Macrophomina phaseolina*) is a widespread soil-borne fungus but a weak pathogen. It attacks plants that are moisture-stressed late in the season when soil temperatures are warm. In lupins, the first symptom is premature senescence of individual or patches of plants within a crop. The stem and taproot of infected plants will have an ash-grey discolouration (when split open) due to masses of tiny black microsclerotia embedded in the tissue. *M. phaseolina* survives as microsclerotia in the soil and on infected plant debris. The microsclerotia serve as the primary source of inoculum and may persist within the soil up to three years. Charcoal rot can infect a wide range of other legume, oilseed and broadleaf crops and pastures. Cereal crops are not normally infected.

9.14.2 Abiotic root damage

Abiotic damage to root and hypocotyls can cause above ground symptoms similar to root disease. Abiotic stresses commonly contribute to poor root health and often facilitate secondary infection by fungal pathogens. Roots and hypocotyls can be physically damaged through abrasion and obstruction by soil particles, particularly in coarse or rocky soil. Impermeable hardpans and duplex soils can cause damaged or bent taproots and poorly developed root systems. Waterlogging can result in soft discoloured roots, poorly developed root systems and yellowing of plants. Chemical

68 B Coutts (2017) Bean yellow mosaic virus in lupins. DAFWA. https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins?page=0%2C1

damage from triazine or sulfonylurea herbicides or poor fertiliser placement can cause rotting, pruning or reduced development of roots. [69]

9.15 Minor foliar diseases

Grey leaf spot (*Stemphylium botryosum*) causes brown circular lesions on leaves which with age can expand and become ash-grey often causing premature defoliation. Brown 'pockmark' lesions can occur on stems and pods. In severe cases complete defoliation can occur. Current varieties carry effective genes for resistance.

Cladosporium leaf spot (*Cladosporium sp.*) causes dark grey circular spots on flowers and leaves of lupin plants in warm and wet conditions. Drier spring conditions rapidly reduce disease spread and yield reductions rarely occur.

Powdery mildew (*Erysiphe polygoni*) affects all lupin species. Typically it is seen as a white powdery growth on leaves, stems and pods. [70]

69 G Thomas, D Huberli (2016) Lupin root diseases: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management?page=0%2C4

70 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

Plant growth regulators and canopy management

Not applicable for this crop.

Crop desiccation/spray out

Key messages

- Lupins are an advantage to rotations as they can be crop-topped to prevent herbicide resistant weeds setting seed.
- Desiccation can be used but is rarely needed. To ensure minimal risk to grain quality, check the seed before desiccation.
- Crop-topping is used mainly to target annual ryegrass in lupin crops and may not control wild radish and other brassica weeds as they have similar developmental stage to lupin.
- Timing is more critical than the rate, so rate should be adjusted depending on the target. Timing for desiccation is just after the crop starts to yellow (senesce).
- The crop will be ready to harvest between 5 and 10 days after desiccation.
- Do not desiccate crops intended for seed.

Desiccation and crop-topping are well established techniques to improve the rotational fit, benefits and profitability of the pulse crop. While they are essentially the same physical operation of applying a desiccant herbicide close to final maturity of the pulse, they do achieve different objectives and must be applied with care. Windrowing may be considered as an alternative to desiccation. The timing of windrowing is similar to desiccation.

Crop-topping (for weed control) or desiccation can ensure a quicker and more uniform ripening of the crop. Plants growing in wheel tracks may ripen later and usually need to be desiccated for harvest. Timing of desiccation or crop-topping is critical for grain quality because premature desiccation of wheel tracks or later maturing areas in a paddock can lead to grain quality issues in the harvested sample (e.g. green kernel or stained seed coats). [1]

There are three reasons to apply non-selective herbicides late in the season:

1. just prior to harvest to manage late season weeds;
2. in-crop spray topping of annual ryegrass to prevent seed set; and
3. for pre-harvest desiccation of the crop to accelerate or even up ripening to assist with harvest.

Desiccation and crop-topping are used to achieve different objectives. Pulse species differ in their time to maturity, making some unsuitable for crop-topping. Crop-topping is conducted before the target weed species mature, later maturing pulse species will be adversely affected.

The application of herbicides late in the season to prevent weeds setting seed or to desiccate crops must be carried out with caution and in line with herbicide label recommendations. It is essential to check if these practices are acceptable to buyers, as in some situations markets have extremely low or even zero tolerance to some pesticide and herbicide residues. [2]

MORE INFORMATION

Late season herbicide use factsheet.

11.15.1 Desiccation

Desiccation prepares the pulse crop for harvesting by removing moisture from plants and late maturing areas of the paddock.

In seasons with a hot and dry finish, lupin will mature naturally. In some seasons and circumstances, desiccation may be a worthwhile option. The use of desiccants can help to reduce shattering, pod loss and plant lodging during harvest.

1 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

2 GRDC (2010) Late season herbicide use Factsheet. http://www.goodfoodworld.com/wp-content/uploads/2017/09/GRDC_LateSeasonHerbicideUse_FS.pdf

Desiccation is used in albus lupin and can be used (but it is rarely warranted) in narrow-leaf lupin.

Salvage spraying or pre-harvest desiccation is required in some years to desiccate weeds and assist timely harvesting of winter crops. Situations do arise due to late establishing weeds combined with wet and prolonged springs or harvest periods, where salvage spraying may be necessary. Weeds such as skeleton weed, bindweed, melons, sowthistle, prickly lettuce, fat hen and New Zealand spinach can interfere with harvesting whilst weed seeds such as saffron thistle, rough poppy, Mexican poppy and black/field bindweed can contaminate grain. [3]

11.15.2 Crop-topping

Crop-topping aims to stop the seed set in surviving weeds without substantially affecting crop yield and grain quality (Photo 1). Crop-topping is timed for the weed growth stage to control weed seed set from survivors of normal in-crop weed control. Crop-topping is done earlier than desiccation, with some potential loss of yield or quality if not careful. Crop-topping cannot be used in all pulses.

It is effective in early maturing species and is also effective in drying off late maturing weeds to reduce high moisture or contamination of harvested grain. If crop-topping to prevent weed seed set be aware of its limitations and the need for correct timing.

Croptopping is very effective in short to medium maturity varieties. Some varieties are less suitable to crop-topping than others, for example Jenabillup⯑ and Jindalee⯑ flower slightly later and for a longer period than Mandelup⯑, and are therefore at higher risk of damage from crop-topping than Mandelup⯑. [4]

Photo 1: *Desiccation has the added benefit of drying down broadleaf weeds present at harvest.*

Source: Pulse Australia

When used correctly in the appropriate pulse species, the crop will be almost or fully mature and grain quality will be unaffected. Crop-topping is part of an Integrated Weed Management strategy and should not be used as a sole strategy.

The major differences between desiccation and crop-topping are:

- Application timing is different and initiated by different criteria.
- Herbicides for crop-topping and desiccation are not always the same.
- Herbicide rates for desiccation are higher than that required for crop-topping.
- Crop-topping will advance the harvest timing in some pulse crops.
- Neither desiccation nor crop-topping can be used effectively in all pulses.
- Both will cause reduced grain quality and yield if applied at the wrong maturity stage of the crop. [5]

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3 G Brooke, C McMaster (2016) Weed control in Winter crops 2016. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops

4 C Jeisman (2015) Lupin variety sowing guide 2015. PIRSA. https://grdc.com.au/resources-and-publications/all-publications/publications/2016/12/sa-sowingguide2017

5 Pulse Australia. (2015). Australian Pulse Bulletin: Desiccation and croptopping in pulses. http://pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping

11.15.3 Timing

Key points:

- Ideal timing is to crop top lupins that are at 80%+ leaf drop
- Ryegrass should be flowering to soft dough for best results
- Yield reductions of about 5–10% can occur if the lupin crop is not fully mature
- If the target lupin and ryegrass windows are not going to match up and weed control is your highest priority then you may need to consider sacrificing some lupin yield and spray prior to 80% leaf drop.

Timing is critical. [6]

Once a seed has reached physiological maturity (62% to 65%) it is possible to start to use desiccants. At this stage, the stem and leaves are light green to yellow and the leaves are beginning to fall from the plant. In practice, the correct time can be difficult to determine. If desiccating is done too early, some of the seeds may not ripen fully and the cotyledon will remain green instead of turning yellow. Correct timing is a compromise between the earlier and later pods. [7]

If lupins are at 80% or greater leaf drop they can be crop-topped with paraquat with little or no damage to the yield (Photo 2). If a lupin crop has small pods (for example, tertiary pods) at the top of the plant at the time of crop topping then yield penalties may be expected. Leaf drop can be defined as the time when the leaves have turned completely brown. Some leaves turn brown and drop to the ground whereas others stay attached to the plant. All brown leaves can be considered as having dropped.

Photo 2: *A lupin crop at the 80% leaf drop stage is ideal for crop-topping.*

Source: DAFWA

6 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

7 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Timing for weed control

Timing is aimed at the soft dough stage of the target grass weed species, typically annual ryegrass, to stop seed set (Photo 3). If radish is the target, the herbicide should be applied at the pre-embryo stage. In most crops, targeting radish exposes the crop to a heightened risk of crop damage. [8]

Photo 3: *Preventing seed set on all ryegrass escapes is the aim when croptoping pulses.*

Source: Pulse Australia

Annual ryegrass

Trial work, the label and anecdotal evidence agree that the ideal timing to maximise ryegrass control is from the time when the last of the seed heads have emerged to just before the ryegrass hays off. The alternative way of saying this is from flowering of the ryegrass to the soft dough stage. At the firm dough stage, seed set control will be more variable.

When is soft dough?

The following is a guide to assessing the stage your annual ryegrass seed is at. When testing the stage of ryegrass it is best to assess seed located in the middle of the seed head.

Pull seed off and squeeze between your fingers – if the contents that come out are:

- Just sappy liquid – the seed is 'watery ripe'. This is the stage when seed is forming the cell walls that will be filled with starch.
- Milky, white liquid – 'milk stage'. This is when starch is being deposited into the seed. The thickness of the sap denotes early, middle and late milk stages.
- Cluggy, but still soft and like dough – 'dough stage'. As the amount of moisture decreases you move through the dough stages (soft – hard). Eventually no moisture will really squeeze out.
- When there is very limited moisture there isn't anything else being added to the seed and it is at the 'firm or hard dough stage'. When squeezed the seed will compress, be firm and still retain its general form.

8 Pulse Australia. (2015). Australian Pulse Bulletin: Desiccation and croptopping in pulses. http://pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping

- If the seed hardly compresses when squeezed and the seed colour is yellow/ brown you are well on the way to 'ripening'. From this point, it will be too late to get control. [9]

The stages of grain ripening are called milk, soft dough, hard dough, hard kernel, and harvest ripe (Photo 4). Most of the dry matter accumulates during the soft-dough stage. Loss of water gives the kernel a doughy or mealy consistency. At the end of the hard-dough stage, the kernel reaches physiological maturity, water content drops to about 30%, and the plant loses most of its green colour. The kernel contents can be divided with a thumbnail. [10]

Photo 4: *Example of grain in the soft dough stage.*

Source: Jackson and Williams 2006

11.15.4 Application

When spraying, use extreme caution and carefully consider the possibility of spray drift onto susceptible plants – e.g. cotton, canola, lucerne, grapevines, horticultural crops, belah and kurrajong trees.

Diquat at 200 g/L (Reglone®) is registered for pre-harvest desiccation of lupins in the Northern region. Ground or aerial application should be at a rate of 2–3 L/ha. Refer to label for spray timing. The Harvest Withholding period for use in lupin is not stated.

Paraquat 360 g/L (Gramoxone®360 Pro) is registered for in-crop crop-topping of lupins in the Northern region. Product should be applied from the ground at a rate of 280 or 560 mL/ha (+adjuvant). This product can be applied to annual ryegrass when the last ryegrass seed heads have emerged (refer to label for more information). The Harvest Withholding period is 7 days. Reduction in crop yield may occur if the crop is less advanced relative to the ryegrass. [11]

9 A Douglas (2016) Crop-topping pulse crops. DAFWA. https://www.agric.wa.gov.au/lupins/crop-topping-pulse-crops

10 L Jackson, j Williams (2006) Small grain production part 2: Growth and developments of small grains. University of California, http://anrcatalog.ucanr.edu/pdf/8165.pdf

11 G Brooke, C McMaster (2016) Weed control in Winter crops 2016. NSW DPI. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops

MORE INFORMATION

GRDC Preharvest herbicide use fact sheet

Table 1 details the registered herbicides for use when crop-topping or desiccating lupin. Glyphosate is not registered for seed crops and should not be used in pulses intended for seed production or sprouting.

Table 1: *Exceeding maximum label rates will lead to the detection of chemical residues in excess of the allowable Maximum Residue Level (MRL) jeopardising market access and the future of the Australian grains industry. Note that it is imperative that only registered products are used at label rates.*

Herbicide	Example trade names	Operation	Rate	Withholding period
Diquat 200 g/L	Reglone®	Desiccation	2 to 3 L/ha	Grazing/ stockfeed (GSF): 1 day Harvest: 0 days (lupin, dry pea)
Paraquat 250 g/L	Gramoxone®	Crop-topping	400 to 800 mL/ ha	GSF: 1 day (7 days for horses) Stock must be removed from treated areas 3 days before slaughter Harvest: 7 days
Saflufenacil	Sharpen	Desiccation	34 g/ha plus recommended label rate of glyphosate or paraquat herbicide plus 1 % Hasten or high quality MSO	GSF: 7 days Harvest: 7 days

GSF - Withholding period for grazing or cutting for stock food. **Note: Observe the Harvest Withholding Period and GSF for each crop.**

Source: Pulse Australia

11.15.5 Retaining seed from crop-topped lupins

Avoid crop-topping crops that will be kept for seed. Some research has shown that if lupins are sprayed late enough, that is 80–100% leaf drop, that there is little effect on the germination percentage of the lupin seed. However, it is likely that crop topping even at this late timing will have detrimental effects on lupin seed quality (for example, reduced vigour) due to uneven ripening.

- It is best to avoid retaining seed from a crop-topped paddock
- If possible harvest lupin seed from a crop that has not been crop-topped
- If this is not possible then choose lupin seed from an area of crop that was most advanced (ideally beyond 80% leaf drop) when it was crop-topped
- Clean lupin seed and store it without applying any seed treatments. Grading out small seed may also help to maximise the germination percentage of the lupin seed.
- Conduct a seed germination test. For more information on germination testing, see Section 2: Pre-planting, section 2.3.2 Seed germination and vigour. [12]

12 A Douglas (2016) Crop-topping pulse crops. DAFWA. https://www.agric.wa.gov.au/lupins/crop-topping-pulse-crops

Harvest

Key messages

- The most important management consideration in growing lupins is correct harvest time as losses can be extreme if timed incorrectly. Move from cereal crops to lupins when the crop is in the optimum harvest window.
- Lupins should be harvested as soon as they are ripe. Delays can result in significant yield losses due to lodging, pod shattering and pod drop. Lupins must be harvested within three weeks of maturity.
- Harvest in the cool of the day or at night. Harvesting in the heat of the day will result in unacceptable losses
- High shattering losses can occur in varieties such as Mandelup⌽ when harvest is delayed past maturity.
- A moisture meter should be used to determine when the lupin crop is ready, and harvest should start as soon as the moisture content reaches 14%. In some seasons this will occur when the stems are still pale green. [1]
- Ideally retain seed from grain harvested before rain. Weather damaged grain is more susceptible to poor germination, low vigour and degradation during storage and handling, so extra care is needed. Harvest at low moisture and cool temperatures.
- Headers easily damage seed, as does excessive handling during harvesting, grading and sowing. Rotary headers cause less damage. Use a low header drum speed and open the concave; and minimise subsequent handling. [2]

When it comes to delivering high-quality pulses likely to attract price premiums from buyers, there are several factors to consider. Lupin grain quality and prices can suffer if there is mechanical damage, pod drop and shattering (Photo 1). Moisture levels at harvest also affect the quality of grain in storage.

Photo 1: *Lupin harvest in the early evening when weather conditions are favourable.*

Source: DAFWA

1 GIWA. Lupins - Production. http://www.lupins.org/production/

2 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

12.1 Windrowing

Windrowing or swathing involves cutting the crop and placing it in rows held together by interlaced straws, supported above the ground by the remaining stubble (Photo 2). Windrowing can be a useful management tool when:

- the crop is uneven in maturity, or the climate does not allow for rapid drying of the grain naturally
- there is a risk of crop losses from shedding and lodging
- if growers have a large area to harvest, windrowing can be a management tool as it allows more time to harvest the crop within the optimum harvest window. Grain is at lower risk of damage in the windrow than when left standing
- Avoid pod shatter and drop in narrow-leafed lupin crops resulting in increased harvest yield
- Avoid problems where the header reel gets in the way of tall crops during harvest
- Avoid green material such as late weeds which can contaminate the grain and cause problems during storage due to high moisture
- Manage very slow and unevenly ripening crops in mild seasons
- Increase header efficiency.

Photo 2: *Directing chaff into a narrow windrow using a custom-made chute.*

Source: GRDC

Windrowing and crop desiccation are viable options in lupins, particularly for crops with variable maturity or high weed burdens. [3] Windrowing lupins is a useful harvest management tool for both narrow-leafed and albus lupins.

Windrowing should be used as an optional management tool and not an essential part of growing lupins.

3 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

Windrowing for weed management

Windrowing can be used to help reduce seed set of weeds such as annual ryegrass, saffron thistle and wild radish. Growers must be aware that some weed seed may be mature before the lupin crop is matures. Crops windrowed to maximize weed control generally incur a yield penalty.

12.1.1 Timing

Correct windrow timing is essential. If lupins are windrowed too early, yield will be sacrificed and quality will be reduced due to a high number of shriveled seeds. Leaving it too late will result in a high risk of pod shattering and pods being knocked off during the windrowing operation.

To properly judge the crop maturity, sample from a number of sites within the paddock. In practice, the correct time can be difficult to determine.

Windrowing should occur when the top pods, those last to mature, are passed physiological maturity and are in the dry-down phase. The lowest, most mature pods on the primary or main spike will be close to ripe and have a seed moisture content of approximately 40%. At this stage, the average seed moisture for the whole plant will be about 60%. The cotyledons will be turning from bright, fleshy green to yellow (Photo 3).

Sampling plants to determine maturity

Pods should be removed from plants branch by branch, keeping pods from each branch separate. Check the least mature top pods first.

Remove seeds from pods and peel the seed coat to reveal the cotyledons. On the primary or main spike which flowers first, they should be light grain. Cotyledons from the second and third order lateral branches should be dark green, but past the bright watery green stage (Photo 3, right hand seed).

Photo 3: *Pod wall, seed coat and cotyledon colours of narrowleafed lupin (left) and albus lupin (right) at the correct stage of maturity to windrow. Pods are from the main stem, first-order lateral, second-order lateral and third-order lateral.*

Source: NSW DPI

Windrow timing is a compromise between the earlier and later pods. The window for windrowing lupins is quite large compared to canola and is in the order of 7 to 14 days depending on seasonal conditions and the rate of dry down.

Albus lupins

When windrowing albus lupins it is important not to start too early as immature seeds will become shriveled when dry. These reduce the quality and can cause problems meeting delivery standards. Windrowing can be delayed as long as pods are not going to be lost during the windrow operation.

Narrow-leafed lupins

Windrowing should not be delayed in narrow-leafed lupins as they have a tendency to drop pods, especially as the cutter bar of a header or windrower hits them. If dry conditions prevail, windrow at night of in the early morning when dew will help to minimise shattering.

12.1.2 Harvesting windrowed lupins

Windrowed lupins mature in a similar time as a standing crop and are ready to harvest 10–30 days after windrowing. They dry out following rain as long as the windrows are not too big. If harvest is very wet there is little difference in the likelihood of seed sprouting between windrowed and standing lupins.

Windrows are best harvested with a pickup front which increases harvest speed and reduces losses (Photo 4). [4]

Photo 4: *Harvesting narrow-leafed lupins using a pickup front.*

Source: NSW DPI

12.2 Harvesting lupin

12.2.1 Timing

Early harvest of pulses is critical because delays can result in significant yield losses due to lodging, shattering and pod loss. Grain quality can also suffer. Moisture levels at harvest affect the quality of the grain in storage. Delaying harvest will allow grain to become more brittle and so susceptible to cracking and splitting. Also, moulds and diseases such as black spot on peas can increase on the pods and seeds. Seed damage from pests such as pea weevil is reduced by early harvest and fumigation.

After physiological maturity, lupin seed dries down further to reach harvest maturity. Seed quality is best when the seed moisture content is between 13% and 14% (Photo 5). At higher moisture contents the seed will require aeration or drying for longer-term storage. Take special care when harvesting seed for next year's crop. Harvest it as soon as it is mature; i.e. when seed moisture content reaches 14%.

4 D Carpenter (2000) Windrowing lupins. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/157237/pulse-point-10.pdf

Photo 5: *Lupin pods at harvest maturity.*

Source: DAFWA

Note that, in some seasons, harvest maturity can occur when the stems are still pale green (Photo 6).

Photo 6: *Paddock of lupin ready for harvest. Though the pods are brown, some of the stems can remain green.*

Source: GRDC

Timing is critical to maximise yields. If lupins are not harvested within one week of maturity shedding may cause significant yield losses, especially in hot conditions. Losses of between 5–40% can occur as pods shatter entering the header or shattering when hit by the header, not even making it into the header. Pods are prone to shattering if left too long after maturing, especially albus lupin. Harvesting at or below 10% moisture can increase the amount of bruised and cracked seed (Photo 7), greatly reducing quality. This will reduce the germination percentage of the seed when it is sown the next year. A seed can be damaged even though the seed coat may appear undamaged. [5]

5 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 7: *Cracking of albus lupin seeds due to handling at the wrong moisture content.*

Photo: Lowan Turton, Source: NSW DPI

12.2.2 Weather conditions

It is recommended that growers harvest at night or in the early morning with dew to minimise shattering and pod drop. [6] Harvest losses can also be substantially reduced by harvesting when humidity is high. Lupin plants strip well during the night and early morning, do not harvest in the middle of the day when it is very hot. In some cooler southern environments, daytime temperatures often do not become warm enough to cause major problems for harvest, however this is less common in the Northern region. In these areas it may be better to harvest the crop as quickly as possible rather than swapping between lupin and cereals. [7]

Wet harvest

Weather damage occurs when grain is subjected to wetting at harvest. Generally, grain will absorb moisture and start the chemical process that eventuates in germination; this may be indicated by discolouration or wrinkled and loose seed coats, especially in pulses. When pre-harvest moisture is significant the seed will swell, often splitting the skin covering the growing point. This seed is referred to as being sprung. Once this has occurred the chemical reactions in the seed have greater access to oxygen and proceed at a faster rate. If sufficient and prolonged moisture is available the embryo will grow and shoot, completing the germination process. However, if moisture is lacking and the seed dries the process will be incomplete. Provided the seed dries out before the embryo starts to grow this seed could still be viable for sowing. Much of a sprung seed's energy store will have been used, greatly reducing the seed's ability to complete the germination process. Seeds will often be lighter and seedling vigour is often markedly reduced.

Conditions that favour sprouting are also conducive to fungal growth. Sprung seed is more susceptible to fungal attack and physical damage by handling. It is also more vulnerable to disease and rotting once sown.

6 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

7 I Pritchard (2015) Lupin essentials – growing a successful lupin crop. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4

MORE INFORMATION

Saving weather damaged grain for seed factsheet

The harvest of lupins can occur before cereals after rainfall due to the fact that delivery standards for moisture are higher (14%) and the crop architecture makes them dry out quicker than thick cereal crops.

In wet harvests, when weather damage is occurring, it is important that retained seed is harvested as a priority but only at low moisture content. This is especially important where there is no aeration drying on-farm. If heat drying is used extreme care should be taken not to further damage seed quality. Generally, harvesting at a moisture content of about one per cent below receival standard is considered appropriate. Some pulse grains, particularly lupins are very susceptible to damage if harvested at very low moisture content. Where grain has swollen and then shrunk, seed coats will have been stretched and can become wrinkled and loose. The kernel of pulses can also become very brittle and break during handling. Harvester settings and handling processes must ensure that seed coats and kernels are not damaged. Damaged seeds will deteriorate rapidly. [8]

12.2.3 Handling

Pulses are damaged each time they are moved, so farm operations should be planned to minimise grain movement. Avoid excessive handling, as lupin seed is easily damaged. Damage can occur during harvest, grading and sowing. Handling after seed has dried below 14% moisture greatly increases cracking, which reduces germination. [9]

Tubulators or grain belt conveyors cause less damage than augers. When using augers, run them slowly but full. Augers with large clearances between flighting and casing tend not to crush the grain as much as those with close fitting flightings. Loaders which throw or sling, rather than carry the grain, can cause severe reductions in germination rates. [10]

12.2.4 Grain quality and cleaning

It is extremely important to monitor the quality of grain before and during harvest. Seed coat and kernel (cotyledon) can be discoloured by crop topping or premature desiccation in parts of the paddock if ripening is uneven. Pulse samples showing no header damage will always be more acceptable to a buyer, particularly if the product is for human consumption. Staining of seed caused by green plants in the crop or admixture of splits, weeds, stones, etc., will only reduce the value of grain and can lead to dockages.

Recleaning of samples after harvest is sometimes necessary. Cereals can be cleaned from most pulses with a 3 or 4 mm rotary screen. The 3.75 mm slotted screen is popular and will help screen out split grain. The paddles or agitators in rotary screens should be either new or sufficiently worn so that the grain being harvested cannot jam between the outside of the paddle and the rotary screen. Screens or paddles can be damaged beyond repair if the grain jams. Fitting the screens with a spacer will provide additional clearance and so avoid the problem. Dirt and most small weed seeds can be separated in rotary screens, however the dirt will increase component wear.

Remember, harvesting is the last stage in producing a quality product for the market - do not be complacent in pre-harvest crop management or in setting up the header correctly. [11]

8 GRDC (2011) Retaining seed Factsheet: Saving weather damaged grain for seed. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/01/grdc-fs-retainingseed

9 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

10 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

11 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

12.3 Harvester settings

Pulses are easily threshed, so concave clearances should be opened and the drum speed reduced (Table 1). For lupins, keep drum speed below 500 rpm. This will reduce damage to the embryo and help to ensure a high germination percentage. The seed embryo is very sensitive to impact if it becomes dry and brittle. Even seed with no visible damage may have low percentage germination if it suffered a high impact when its moisture content was low. [12]

Allowing some trash to enter is better than thrashing too hard to get a spotless sample with more damaged seed. [13]

Table 1: *Harvester settings for harvesting lupins.*

Reel speed	Slow
Spiral clearance	High
Thresher speed	400–600
Concave clearance	10–30 mm
Fan speed	High
Top sieve	32 mm
Bottom sieve	16 mm
Rotor speed	700–900

Source: Grain Legume Handbook

12.3.1 Modifications and aids

A straw chopper may be of value to chop up the stubble and spread it uniformly. Crop lifters are not required unless the crop is badly lodged or late-sown and drought-affected. Set the finger tyne reel to force material down onto the front. For example, moving the broad elevator auger forward can improve the feeding of light pulse material.

Vibration due to cutterbar action, plant on plant, reel on crop impact and poor removal of cut material by the auger all cause shattering and grain loss, especially on hot days and if the crop is very dry.

Finger reels are less aggressive than bat reels and cause fewer pod losses. Double acting cutterbars reduce cutterbar vibration losses. Four finger guards with open second fingers also reduce vibrations (Photo 8).

12 I Pritchard (2015) Lupin essentials – growing a successful lupin crop. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4

13 K Smith, D Carpenter (1999) Albus lupins. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/157169/pulse-point-08.pdf

Photo 8: *Finger tyne reel with four finger guards and pen second fingers to reduce vibrations.*

Source: GRDC

A lupin breaker is a cheap and simple device which will increase harvesting capacity to reduce grain loss. It is a small serrated plate which attaches to the front spiral and creates an aggressive, positive feed action to clear cut material from the front of the knife. There are other options available to improve lupin harvesting:

Aussie-Air

Aussie-air directs an air blast through reel fingers, in either heavy and light crops. The manufacturer claims an extra 15 horse power (hp) is required to drive an Aussie-Air but there is also less horse power. requirement because of wider concave clearances. The actual hp required should be no more than for a heavy cereal crop.

Harvestaire

Harvestaire replaces reel with a manifold that directs a blast of air into the front. The manifold causes some interference with the incoming crop; correct orientation of air blast is very important; an optional secondary fan to increase the air blast is worthwhile; the device is more effective in light crops.

Vibra-mat

Vibra-mat is a vinyl mat that vibrates with the knife, stops bunching at the knife of open front headers and helps the table auger to clear cut materials; its chief advantage is that this device is very cheap. It is more effective in light crops. It is important to match ground speed to table auger capacity and crop density - too slow and the plants will not have enough momentum to carry to the front, too fast and the cut crop will not be cleared from behind the knife.

Extension fingers

Plastic extension fingers, approximately 30 cm long, which fit over existing fingers can save significant losses, for little financial outlay, at the knife. Pods which would have fallen in front of the knife are caught on the fingers and pushed into the comb by the incoming crop.

Use extended fingers to help trap pods. Grower reports suggest pod loss is reduced if draper fronts are used. [14] Plastic extension fingers fitted to the knife of a harvester can save significant losses for little financial outlay. Pods that would have fallen in front of the knife are caught on the fingers and pushed into the comb by the incoming crop (Photo 9). [15]

Photo 9: *Plastic extension fingers fitted to harvester.*

Photo: Gordon Cumming

Extended fronts

Extended fronts are now available for some headers and reduce losses at the knife by increasing the distance between the knife and auger to a maximum of 760 mm. This helps stop losses from material bunching in front of the auger, where pods can fall over the knife and be lost.

Platform sweeps®

Platform sweeps® are used in conjunction with extended fronts and consist of fingers which rake material towards the auger to help eliminate bunching. They can also be used on conventional fronts.

Draper fronts

Draper fronts such as MacDon® and Honeybee® have large clearances behind the knife and carry the crop to the elevator. The front can also be used for cereals without modification. [16]

Note that costs and benefits must be assessed as a small area of lupins may not justify the cost of some of the above modifications.

14 P Matthews, D McCaffery, L Jenkins (2017) Winter crop variety sowing guide 2017. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/711246/Winter-crop-variety-sowing-guide-2017-downsized.pdf

15 T Weaver. (2015). Ground Cover Issue 118: Profitable pulses – it's all about the harvest window. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-118-Sep-Oct-2015/Profitable-pulses-its-all-about-the-harvest-window

16 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

MORE INFORMATION

Ag Shield Cross Auger

Cross augers

Cross Augers kits are gaining popularity for use in canola and pulse crops. Draper headers are often the best way to harvest most cereal crops but are more difficult to use in peas, canola, mustard, and some pulse crops. Bunching and catching can cost time and reduce yield. Cross auger kits can reduce these problems. These augers span the whole header and drag material in right from the corners – there is no dead space at the ends like some of the other units that are available. Even really fluffy material is dragged into the feeder house smoothly. The reduces lumps surging through the harvester, which would normally overstress drives and overload sieves. [17]

12.4 Fire prevention

Key points:

- Most harvester fires start in the engine or engine bay
- Others are caused by failed bearings, brakes and electricals and rock strikes
- Regular removal of flammable material from the engine bay is urged
- More regular clean downs with a high pressure air compressor are required. This may be as often as each stop at the chaser bin.
- Static electricity can start fires in headers when harvesting pulse crops.

Harvesting season in Australian cropping areas is the most stressful time for farmers as they glean finished crops. Ideally, harvest occurs under hot dry conditions, but the risk of fire is extreme and a fire can damage crops, machinery and property, not to mention the lives of the community as well.

With research showing an average of 12 harvesters burnt to the ground every year in Australia (Photo 10), agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses. [18]

A review of the causes of header fires concluded that 75% of the fires started in the engine bay and others from failed bearings, electrical problems and rock strikes. [19]

Photo 10: *GRDC figures show that there are 1000 combine harvester fires in Australia each year.*

Source: Weekly Times

17 Ag Shield (2013) Cross Auger Kits. http://www.agshield.com/files/Cross%20Auger/cross_auger_June_13.pdf

18 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

19 G Quick (2010) An investigation into combine harvester fires. http://pulseaus.com.au/storage/app/media/blog%20assets/HARVESTER%20FIRES%20-%20Graeme%20Quick%20-%20Final%20Report.pdf

Many of the pulse crops come with an increased fire risk because of certain characteristics of the residues. Lupins have fine residue that powders easily and create higher risk of ignition. Advice from Canada suggests that diseased crop leaves are a higher risk of fire at harvest.

All of these pulse crop residues may well have much lower ignition temperatures than cereal crops. When harvesting lupin, more regular clean downs with a high pressure air compressor are required.

The proximity of flammable material to heat sources such as exhaust manifolds and turbochargers with high ambient temperature, low humidity and windy conditions in the paddock make this an explosive situation, even under ideal conditions.

Heated ignition sources can be in different areas, including:

- around the engine bay of the header such as the exhaust manifold or the tubocharger where temperatures can get up to 650°C
- mechanical failures from bearings
- sparks from electrical short circuit
- striking metal fences or rocks to cause a spark
- static electricity from moving parts or operators clothing
- foreign objects that are taken into the header

Fuel sources can include:

- the dried standing crop itself
- crop residue that has been chopped finely to create an ideal fuel for instant ignition.
- flammable fuels and oils used in the header.
- dust that carries crop residue

Oxygen (air) is required for a fire to burn. Air is being blown around inside and out of the header throughout the harvesting process and is an important component of harvest fires.

Static electricity is often blamed, but the evidence shows that this is a minor risk, even though it is common to get a build up from many parts of a header. The energy to ignite crop residue is not enough in a static electrical discharge. [20]

Machinery failure is in many cases responsible for fires starting so it is critical that all growers undertake scheduled harvester operation checks and regular maintenance leading up to and throughout harvest in an effort to reduce the risk of fire. Many pre-harvest preventative maintenance checks tie into what growers already do on a regular basis, such as checking belts, hoses and wiring for damage.

Growers should also be regularly monitoring bearing operation temperatures with an infra-red thermometer to detect rapid increases in temperature, indicating imminent failure. Oil seals should also be inspected. A dripping line or weeping seal needs to be repaired prior to harvest, otherwise that could become a fire hazard.

Some growers use exhaust insulation blankets (such as those used in the mining and racing car industries), alumina-silica materials on exhausts and turbo chargers to reduce fire risk. This is an effective way of reducing fire ignition sources, but growers need to be careful with the impact such insulators could have on engine and turbo operation temperatures and any warranty implications.

Harvester hygiene is important; conduct regular clean-outs during harvest and exercise caution when harvesting leafy pulse crops, as these are renowned for dust build-up.

It is also important to have properly functioning fire extinguishers on harvesters. Machine-mounted fire suppression options on the market have come down in price so growers should consider having a fire suppression system fitted.

20 P Bowden (2016) Fire risk when harvesting pulses. Pulse Australia. http://pulseaus.com.au/blog/post/avoiding-harvester-fires

Abide by state-based grain harvesting codes of practice and declared harvest bans, and observe the Grassland Fire Danger Index (GFDI) protocol on high fire risk days. [21]

Harvester fire reduction checklist

1. Recognise the big four factors that contribute to fires: relative humidity, ambient temperature, wind and crop type and conditions. Stop harvest when the danger is extreme.
2. Focus on service, maintenance and machine hygiene at harvest on the days more hazardous for fire. Follow systematic preparation and prevention procedures.
3. Use every means possible to avoid the accumulation of flammable material on the manifold, turbocharger or the exhaust system. Be aware of side and tailwinds that can disrupt the radiator fan airblast that normally keeps the exhaust area clean.
4. Be on the lookout for places where chaffing can occur, such as fuel lines, battery cables, wiring looms, tyres and drive belts.
5. Avoid overloading electrical circuits. Do not replace a blown fuse with a higher amperage fuse. It is your only protection against wiring damage from shorts and overloading.
6. Periodically check bearings around the harvester front and the machine. Use a hand-held digital heat-measuring gun for temperature diagnostics on bearings and brakes.
7. Maintain fire extinguishers on the harvester and consider adding a water-type extinguisher for residue fires. Keep a well maintained fire fighting unit close-by to the harvesting operation ready to respond.
8. Static will not start a fire but may contribute to dust accumulation. Drag chains or cables may help dissipate electrical charge but are not universally successful in all conditions. There are some machine mounted fire-suppression options on the market.
9. If fitted, use the battery isolation switch when the harvester is parked. Use vermin deterrents in the cab and elsewhere, as vermin chew some types of electrical insulation.
10. Observe the Grassland Fire Danger Index (GFDI) protocol on high fire risk days.
11. Maintain two-way or mobile phone contact with base and others and establish a plan with the harvest team to respond to fires if one occurs. [22]

Using machinery

To preventing machinery fires, it is imperative that all headers, chaser bins, tractors and augers be regularly cleaned and maintained. All machinery and vehicles must have an effective spark arrester fitted to the exhaust system. To prevent overheating of tractors, motorcycles, off-road vehicles and other mechanical equipment, all machinery needs to be properly serviced and maintained. Fire-fighting equipment must be available and maintained—it is not just common sense; it is a legal requirement.

Take great care when using this equipment outdoors:

Be extremely careful when using cutters and welders to repair plant equipment; this includes angle grinders, welders and cutting equipment,

Ensure that machinery components including brakes and bearings do not overheat, as these components can drop hot metal onto the ground, starting a fire.

Use machinery correctly, as incorrect usage can cause it to overheat and ignite.

21 S Watt, B White. (2016). Growers focused on reducing harvester fire risk. https://grdc.com.au/Media-Centre/Media-News/South/2016/11/Growers-focused-on-reducing-harvester-fire-risk

22 Barr R. (2015). Plant of attack needed for harvester fires. https://grdc.com.au/Media-Centre/Media-News/South/2015/10/Plan-of-attack-needed-for-harvester-fires

Be aware that when blades of slashers, mowers and similar equipment hit rocks or metal, they can cause sparks to ignite dry grass.

Avoid using machinery during inappropriate weather conditions of high temperatures, low humidity and high wind.

Do repairs and maintenance in a hazard-free, clean working area such as on bare ground, concrete or in a workshop, rather than in the field.

Keep machinery clean and as free from fine debris as possible, as this can reduce onboard ignitions. [23]

Use of fire suppression systems on the header

There are several systems that can be put on the header to prevent fires or to deal with fire if it starts.

Fire Knock Out will drench the engine bay in fire retardant using a self actuating switch.

Fire Prevention Shield reduces the temperature of the components in the engine bay by drawing air from the cooling fan through a heat exchanger, charging it to higher pressure to clean residues from around the muffler. This effectively reduces residues and temperature to lower the risk of fire. [24]

12.4.1 Harvesting in low-risk conditions

Growers can use the Grassland Fire Danger Index guide to assess the wind speed at which harvest must cease (a GFDI of 35), depending on the temperature and relative humidity (Figure 1).

Step 1: Read the temperature on the left hand side.

Step 2: Move across to the relative humidity.

Step 3: Read the wind speed at the intersection. In the worked example, the temperature is 35°C and the relative humidity is 10% so the wind speed limit is 26kph.

TEMP °C	5	10	15	20	25	30	40	50	60	65	RH%*
15	31	35	38	40	43	45	49	53	56	58	AVERAGE WIND SPEED (KPH)†
20	29	33	36	38	40	43	46	50	53	55	
25	27	30	33	36	38	40	44	47	50	52	
30	25	28	31	33	35	37	41	44	47	49	
35	23	26	28	31	33	35	38	41	44	46	
40	21	24	26	28	30	32	35	39	41	43	
45	19	22	24	26	28	30	33	36	39	40	
TEMP °C	5	10	15	20	25	30	40	50	60	65	RH%*

*RH% *(Relative Humidity rounded down)*
†Wind speed averaged over 10 minutes

Figure 1: *Grassland fire danger index guide.*

Source: CFS South Australia

PODCAST

LISTEN: GRDC Podcasts: Harvester Fires.

MORE INFORMATION

GRDC Reducing Harvester Fire Risk: The Back Pocket Guide

Avoiding harvester fires - pulses

An investigation into harvester fires

Plan of attack needed for harvester fires

A few steps to preventing header fires

23 NSW Rural fire Service. Farm firewise. NSW Government, http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161

24 P Bowden (2016) Fire risk when harvesting pulses. Pulse Australia. http://pulseaus.com.au/blog/post/avoiding-harvester-fires

12.5 Receival standards

Pulse receival and export standards are set nationally by the pulse industry to ensure that market requirements for major end-users are able to be achieved. Whilst they can be perceived by growers to be hard to meet on some occasions, they have enabled Australia to establish a global reputation for the quality of the pulses exported. Export standards are the basis for pulse trade documents.

The Australia Pulse Standards Committee compiles trading Standards through extensive consultation with all sectors of the Australian pulse industry. It is hoped that these standards will facilitate the desire of the Australian pulse industry to provide consistent product of the highest quality into the world market. All sectors of the industry are encouraged to familiarise themselves with both format and content.

There are varied standards for lupin based on end use; e.g. for human or animal consumption.

For information on receival standards for lupin, see pages 71 – 78 in the Australian Pulse Standards 2016/2017.

All pulses must be free from animal excreta, rodents, live insect pests and any chemical not registered for use on stored pulses or in excess of legal tolerances. There is nil tolerances on pickling compounds/seed dressings or any fungicide added to the pulse as a seed dressing and any tainting agents and/or other contaminants imparting an odour not normally associated with that particular pulse.

There is nil acceptance of toxic and/or noxious weed seeds which are prohibited by state laws against inclusion in stock feed.

It is understood that as Minimum Standards they may not be tight enough for the requirement of some buyers. Suitable qualifications to any Standard can be made as agreed between all parties concerned to represent the basis for better quality consignments.

It should also be understood that these are Australian Industry Standards and do not take into account specific overseas country quarantine restrictions (such as prohibited weed seeds, disease status or contaminant levels) or the requirements of the Export Control Act (1982) and its subordinate legislation.

Individual commodity traders are responsible for ensuring that specific country requirements and those pertaining to compliance with the Export Control Act (1982) are included as additional specifications on the contract.

MORE INFORMATION

Receival and trading standards

Lupini bean – a bitter contamination risk for sweet albus lupins

12.5.1 Bitter seed contamination

If a crop of albus lupins has 99% sweet seed with 20 mg/kg, and 1% bitter seeds with 20 000 mg/kg, the overall alkaloid level would be about 220 mg/kg. This is above the acceptable Food Standard of 200 mg/kg for lupin alkaloids. Pulse Australia's Receival and Export Standards for albus lupins specify that bitter contaminants must be no more than 2 seeds/200 g. With an average albus seed size of 0.35 g, that equates to a bitter seed frequency threshold of 1 in 285 seeds (0.35%). Clearly, both the Food and Receival standards are at risk of being breached if sweet crops become contaminated at even very low frequency. The future of the Australian albus lupin industry depends on the ability to supply 100% sweet seed. [25]

For more information on preventing bitter seed contamination, see Section 2: Pre-planting, section 2.3.3 Bitterness in Albus lupin.

25 D Luckett (2010) PrimeFacts: Lupini bean – a bitter contamination risk for sweet albus lupins. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/186672/Lupini-bean-a-bitter-contamination-risk-for-lupins.pdf

12.6 Harvest weed seed management

There are several ways of utilising harvest to lessen the numbers of viable weed seeds, to prevent weed seed returning to the seedbank and then proliferate during the next season. Techniques include harvest weed-seed control (HWSC), windrow burning, and the use of chaff carts, direct baling the Harrington Seed Destructor. It has been shown that these systems have similar effectiveness. [26]

12.6.1 Harvest weed-seed control

Many Northern grain growers have been a little sceptical about introducing harvest weed-seed control (HWSC) as a tool for combating herbicide resistance. Nationally, HWSC is proven to reduce the weed seedbank, and some weeds of the Northern grains region are suited to this method of control, particularly in a farming environment of increasing herbicide resistance.

Weed-seed capture and control at harvest can add to the effectiveness of other tactics to put the weed seedbank into decline. Up to 95% of annual ryegrass seeds that enter the harvester exit in the chaff fraction. If these can be captured, they can be destroyed or removed.

Lupin is well suited to harvest weed seed control tactics, such as narrow windrow burning, chaff cart, Harrington seed destructor, where weed seed is concentrated in the chaff stream at harvest.

Harvest as early as possible and collect and burn the lupin residue in narrow. Burning lupin residue generates temperatures hot enough to destroy ryegrass and radish seed. For best results, avoid grazing the lupin stubble and burn the windrows in a light cross-wind. Alternatively, separate the residue from the chaff (containing weed seeds) and funnel the chaff fraction into a chaff line or on tramlines to rot down.

Western Australian farmers and researchers have developed several systems to effectively reduce the return of annual ryegrass and wild radish seed into the seed bank, and help put weed populations into decline.

A key tactic for all harvest weed-seed control operations is to maximise the percentage of weed seeds that enter the header. This means harvesting as early as possible before weed seed is shed, and harvesting as low as is practical, e.g. at 'beer-can height'.

Northern weeds suited to HWSC

- Definitely—turnip weed, wild radish and African turnip weed are potentially very good candidates for HWSC.
- Definitely in winter crops—annual ryegrass and wild oats. Wild oats shed seed at about 2% per day and ryegrass at 1% a day, but it is still worth using HWSC at the start of harvest.
- Possibly in winter crops—barnyard grass and feathertop Rhodes grass are known to shed their seed in summer crops, but where they germinate in spring in winter crops they may be suitable candidates for HWSC.
- Possibly in summer crops—feathertop Rhodes grass provides an opportunity for HWSC in summer crops where there is a high percentage of seed retention at the start of harvest. [27]

MORE INFORMATION

GRDC's Tactics for managing weed populations

26 M Street and G Shepherd (2013) Windrow burning for weed control: WA fad or a viable option for the east? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Windrow-burning-for-weed-control-WA-fad-or-viable-option-for-the-east

27 T Somes (2016) Can harvest weed-seed control work for the North? Ground Cover. Issue 124, September–October 2016. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-124-SeptemberOctober-2016/Can-harvest-weedseed-control-work-in-the-north

12.6.2 Narrow windrow burning

During traditional whole-paddock stubble burning, the very high temperatures needed to destroy weed seeds are not sustained for long enough to kill most weed seeds. However, by concentrating harvest residues, which includes weed seeds, into a narrow windrow, the fuel load is increased and the period of high temperatures extends to several minutes, improving the kill of weed seeds (Photo 11).

Photo 11: *Narrow windrow burning the Northern region.*

Photo: P Heuston.

Windrow burning: the WA experience

Windrow burning has been widely adopted in Western Australia as an option for dealing with weed seeds that are resistant to herbicides. It is used as part of an integrated harvest weed-management strategy that includes these considerations:

- Continued reliance on herbicides alone is not sustainable in continuous-cropping systems. Rotating herbicides alone will not prevent the development of resistance.
- The early implementation of windrow burning will prolong the usefulness of herbicides, not replace them.
- Windrow burning is the cheapest non-chemical technique for managing weed seeds present at harvest.
- Even with higher summer rainfall, windrow burning is a viable option for NSW cropping systems.
- Windrow burning is an effective weed-management strategy, even in the absence of resistance.
- Narrow windrow burning is rapidly being replaced by chaff lining in southern NSW due to social pressure and stress involved with burning. [28]

MORE INFORMATION

Section on narrow-windrow burning in GRDC's Tactics for managing weed populations

Windrow burning for weed control: WA fad or a viable option for the east?

The nuts and bolts of efficient and effective windrow burning

VIDEOS

WATCH: Windrow burning in Northern NSW

WATCH: Burning Barriers to windrow burning in NSW

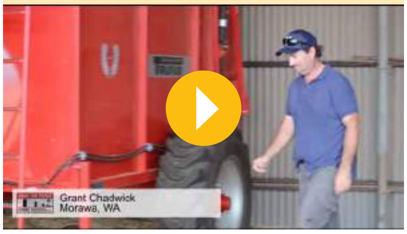
28 M Street and G Shepherd (2013) Windrow burning for weed control: WA fad or a viable option for the east? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Windrow-burning-for-weed-control-WA-fad-or-viable-option-for-the-east

VIDEOS

WATCH: Chaff carts – P. Newman

WATCH: Chaff tramlining tackles weeds

WATCH: Chaff cart key part of plan to eradicate weeds



MORE INFORMATION

Section on chaff carts in GRDC's Tactics for managing weed populations

12.6.3 Chaff carts

Chaff carts are towed behind headers during harvest to collect the chaff fraction (Figure 12). The chaff that is collected is dumped into piles and then burnt the following autumn or used as a source of stock feed.

Chaff carts will collect and remove up to 85% of annual ryegrass and wild radish seeds that pass through a header. The chaff collected this way must be managed to ensure the seeds are removed permanently from the cropping system. This can be done by burning in the following autumn or by removing the chaff from the paddock and using it as a livestock feed. [29]

Photo 12: *Chaff cart in action (*

Photo: A. Storrie

12.6.4 Bale-direct system

The bale-direct system uses a baler attached to the harvester to collect all chaff and straw material (Figure 13). This system requires a large baler to be attached to the back of the harvester. As well as removing weed seeds, the baled material has an economic value as a livestock feed. Header-towed bailing systems were developed in Western Australia by the Shields family.

29 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

MORE INFORMATION

Section on bale-direct systems in GRDC's Tactics for managing weed populations

Small and large baler projects of the Shields family

Photo 13: *Bale direct harvester on a Northern region farm.*

Photo: Penny Heuston

12.6.5 Harrington Seed Destructor

The integrated Harrington Seed Destructor (iHSD, Figure 14) is the invention of Ray Harrington, a progressive farmer from Darkan, WA. Developed as a trail-behind unit, the iHSD 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 to the use of windrow burning, chaff carts and baling. [30]

The chaff deck places the chaff exiting the sieves of the harvester on to permanent wheel tracks. Growers using chaff decks have observed that few weeds germinate from the chaff fraction and believe that many weed seeds rot in it. A permanent tramline farming system is necessary to be able to implement the chaff deck system. [31]

30 GRDC (n.d.) Section 6. Managing weeds at harvest. GRDC, https://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

31 Roberts P. (2014). New systems broaden harvest weed control options. GRDC. https://grdc.com.au/Media-Centre/Media-News/West/2014/11/New-systems-broaden-harvest-weed-control-options

VIDEOS

WATCH: A beginner's guide to harvest weed seed control

MORE INFORMATION

Section on the Harrington Seed Destructor in GRDC's Tactics for managing weed populations

Chaff deck concentrates weeds in controlled traffic

Photo 14: *The Harrington Seed Destructor.*

Source: GRDC

Storage

Key messages

- Lupin seed stores much better than cereals and are more resistant to insect attack.
- Lupin should be harvested and stored at 14% moisture content.
- Pulses stored above 12% moisture content require aeration cooling to maintain quality.
- Meticulous hygiene and aeration cooling are the first lines of defence against pest incursion.
- Fumigation is the only option available to control pests in stored pulses, which requires a gas-tight, sealable storage.
- Avoiding mechanical damage to pulse seeds will maintain market quality, seed viability and be less attractive to insect pests.

Storing pulses successfully requires a balance between ideal harvest and storage conditions. Harvesting at 14% moisture content captures grain quality and reduces mechanical damage to the seed but requires careful management to avoid deterioration during storage.

Many of the quality characteristics of the grain from these crops are in the appearance, size and physical integrity of the seed. Mechanical seed damage, discolouration, disease, insect damage, split or small seeds will downgrade quality and market value. Buyers prefer large, consistently-sized seed free of chemical residues for easy processing and marketing to consumers. [1]

VIDEOS

WATCH: GCTV Stored Grain: Storing Pulses

13.1 How to store product on-farm

A recent trend has been increased use of on-farm storage. Much of Australia's grain production is now stored on-farm before delivery to bulk handling sites. The Australian Bureau of Statisics estimates on-farm storage is growing by 4.8% p.a. In 2011, it was estimated that growers on the east coast had an average 11 million tonnes of on-farm storage. This allows farmers to maximise marketing opportunities and minimise storage and handling costs. [2]

To discourage mould growth and insect infestation, the moisture content of lupin seed stored on-farm for the next season should not be over 13%. If the moisture content of harvested grain is too high, aerated storage will prevent spoilage. Alternatively, moving the grain from one silo to another on a warm dry day can help reduce moisture content by 1–2%. [3] Seed stored with high moisture content can deteriorate, particularly if stored at high temperatures.

13.1.1 On-farm storage options

Grain storage systems come in a range of shapes and sizes to meet farm requirements and careful planning is needed to optimise an on-farm grain storage facility investment. According to the option selected, on-farm grain storage systems can provide a short-term or long-term storage facility. Depending on the goal of on-farm storage, whether it be access to improved markets or simply to maximise harvest efficiency, there are a number of options available.

Costs and storage flexibility can vary between grain storage options as can longevity of the investment. Table 1 identifies the major on-farm grain storage options, their advantages and disadvantages.

1 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

2 PricewaterhouseCoopers. (2011). The Australian Grains Industry: The Basics. https://www.pwc.com.au/industry/agribusiness/assets/australian-grains-industry-nov11.pdf

3 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

VIDEOS

WATCH: Over the Fence: On-farm storage delivers harvest flexibility and profit.

WATCH: Stay safe around grain storage.

Table 1: *Advantages and disadvantages of grain-storage options.*

Source: Kondinin Group

Storage type	Advantages	Disadvantages
Gas-tight, sealable silo	Gas-tight, sealable status allows phosphine and controlled atmospheres to control insects Easily aerated with fans Fabricated on-site, or off-site and transported Capacity from 15 t to 3,000 t 25 years or more of service life Simple in-loading and out-loading Easily administered hygiene (cone-based silos particularly) Can be used multiple times in a season	Requires foundation to be constructed Relatively high initial investment required Seals must be maintained regularly Access requires safety equipment and infrastructure Requires and annual test to check gas-tight sealing
Unsealed silo	Easily aerated with fans 7–10% cheaper than sealed silos Capacity from 15 t to 3,000 t Up to 25 year service life Can be used multiple times in a season	Requires foundation to be constructed Silo cannot be used for fumigation Insect control limited to protectants in eastern states and Dryacide® in WA Access requires safety equipment and infrastructure
Grain-storage bags	Low initial cost Can be laid on a prepared pad in the paddock Provide harvest logistics support Can provide segregation options Are ground operated	Requires purchase or lease of loader and unloader Increased risk of damage to grain beyond short-term storage (typically three months) Limited insect control options, with fumigation possible only under specific protocols Requires regular inspection and maintenance, which need to be budgeted for Aeration of grain bags currently limited to research trials only Must be fenced off Prone to attack by mice, birds, foxes, etc. Limited wet-weather access if stored in paddock Need to dispose of bag after use Single-use only

MORE INFORMATION

Grain storage facilities

Grain storage cost–benefit analysis template

Saving weather-damaged grain for seed

Prepare on-farm storage early to protect your harvest

Storage checklist

Grain storage – invest today for the system of tomorrow

Economics of on-farm grain storage: cost–benefit analysis

Economics of on-farm grain storage: a grains industry guide

Saving weather damaged grain for seed factsheet

Storage type	Advantages	Disadvantages
Grain-storage sheds	Can be used for dual purposes	Aeration systems require specific design
	30 years or more of service life	Risk of contamination from dual purpose use
	Low cost per stored tonne	Difficult to seal for fumigation
		Vermin control is difficult
		Limited insect control options without sealing
		Difficult to unload

13.1.2 Weather damage hinders storage

Pulses exposed to weathering before harvest deteriorate more quickly in storage. Chickpeas stored for the medium to long term (6–12 months) continue to age and lose quality. Growers can minimise the effects of seed darkening, declining germination and reduced seed vigour by:

- Lowering moisture content and temperature
- Harvesting before weather damages the grain. [4]

For more information, see Section 12: Harvest, section 12.2.2 Weather conditions.

13.1.3 Handle with care

In addition to harvesting at high moisture content, growers can manage seeds quality at harvest by:

- Minimising the number of times augers shift grain (Photo 1).
- Ensuring augers are full of grain and operated at slow speeds.
- Checking auger flight clearance — optimum clearance between flight and tube is half the grain size to minimise grain lodging and damage.
- Operating augers as close as possible to their optimal efficiency — usually an angle of 30 degrees.
- Using a belt conveyor instead of an auger where possible. [5]

4 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

5 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

Photo 1: *Storage sites, in particular silos, augers and trucks that have held treated fertiliser or alternate products such as pickled (treated) grain can be a source of potential contamination to otherwise clean grain subsequently loaded or moved through that equipment. Where possible, use different storages and augers to handle and store these products.*

Photo: P Jones. Source: GRDC

13.1.4 Optimum moisture and temperature

Research has shown that harvesting pulses at higher moisture content (13%) reduces field mould, mechanical damage to the seed, splitting and preserves seed viability. The challenge is to maintain this quality during storage as there is an increased risk of deterioration at these moisture levels (Figure 1). As a result, pulses stored above 12% moisture content require aeration cooling to maintain quality.

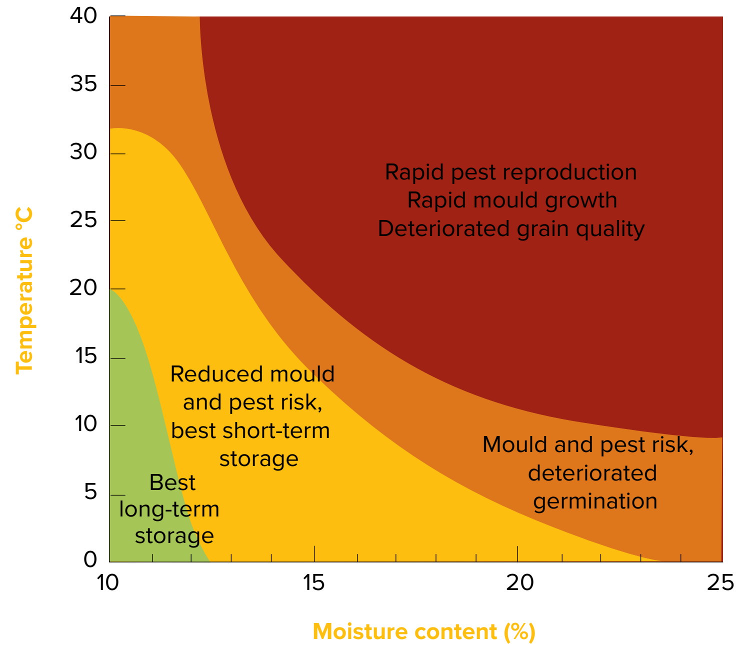


Figure 1: *Effects of temperature and moisture on stored grain.*

Source: CSIRO Ecosystems Sciences

Pulse grain placed in storage with high germination and vigour will remain viable for at least 3 years providing the moisture content of the grain does not exceed 11%. This is especially true for lupins, with farmers often storing grain for years while prices are low, and then successfully planting again when prices increase again. Storage life of pulses is determined by temperature, insects and diseases. Pulses harvested at 13% moisture or higher must be dried before going into storage to preserve seed germination and viability. As a general rule every 1% rise in moisture content above 11% will reduce the storage life of pulse seed by one third. High temperatures in storage will cause deterioration in grain viability. Temperatures of stored pulse grain should not exceed an average of 25°C and preferable the average temperature should be below 20°C. In general each 4°C rise in average stored temperature will halve the storage life of the grain. One practical way of reducing temperatures is to paint the silo white as dark colored silos will absorb more heat. Grain in large silos (over 75 tonnes) will remain cooler as grain is a poor conductor of heat and day - night temperature fluctuations rarely reach 15 cm beyond the silo wall. Small silos (less than 20 tonnes) and field bins will have larger temperature fluctuations and can cause deterioration in grain quality. [6]

Grain Trade Australia (GTA) sets a maximum moisture limit of 13% for most pulses but bulk handlers may have receival requirements as low as 12%. As a general rule of thumb, the higher the moisture content, the lower the temperature required to maintain seed quality (Table 2).

Without aeration, grain is an effective insulator and will maintain its warm harvest temperature for a long time.

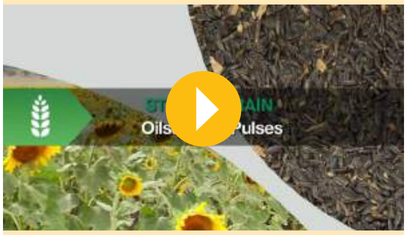
Green pods and grains increase the risk of mould developing during storage — even at lower moisture content. Aeration cooling will help prevent mould and hot spots by creating uniform conditions throughout the grain bulk. [7]

6 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

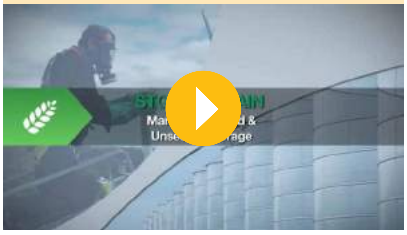
7 GRDC. (2012). Grain storage factsheet: Storing Pulses.

VIDEOS

WATCH: GCTV: Stored Grain: Oilseeds and Pulse Storage



WATCH: GCTV. Stored grain: Managing sealed and unsealed storage



MORE INFORMATION

GRDC Silo buyer's guide

Table 2: *Maximum recommended storage period.*

Moisture content (%)	Grain Temperature (°C) 20	Grain Temperature (°C) 30
14	3 months	N/A
13	9 months	3 months
12	>9 months	9 months

Source: CSIRO

13.1.5 Silos

Silos are the most common method of storing grain in Australia, constituting 79% of all on-farm grain storage facilities nationally. Silos are the ideal storage option for pulses, especially if they are cone based for easy out-loading with minimal seed damage. For anything more than short-term storage (3 months) aeration cooling and gas-tight sealable storage suitable for fumigation are essential features for best management quality control.

Always fill and empty silos from the centre holes. This is especially important with pulses because most have a high bulk density. Loading or out-loading off-centre will put uneven weight on the structure and cause it to collapse. [8]

Gas-tight sealable silos

A gas-tight sealable silo will ensure phosphine, or other fumigants and controlled atmospheres, are maintained at a sufficient concentration to kill insects through their complete life cycle of eggs, larvae, pupae and adult. Be aware of cunning marketing terminology such as 'fumigatable silos'. Although such a silo might be capable of sealing with modifications, a gas-tight sealable silo needs to be tested onsite to meet Australian Standard (AS 2628–2010) after installation. Gas-tight sealable silos also can be used for alternative methods of insect control including controlled atmospheres of inert gasses, such as carbon dioxide or nitrogen. Current costs of using these gases (between $5 and $12/tonne to treat stored grain compared with $0.30 per tonne using phosphine) carbon dioxide and nitrogen atmospheres will arguably be used solely by niche growers, such as organic growers, until gas is less expensive.

There is significant work being carried out in lower-cost nitrogen gas generation and if buying a silo, ensure it is gas-tight for future proofing of the investment. [9]

Pressure testing sealable silos

Key points:

- A silo sold as a 'sealed silo' needs to be pressure tested to be sure it's gas-tight.
- It is strongly recommended that growers ask the manufacturer or reseller to quote the AS2628 on the invoice as a means of legal reference to the quality of the silo being paid for.
- Pressure test sealed silos upon erection, annually and before fumigating with a five-minute half-life pressure test.
- Maintenance is the key to ensuring a silo purchased as sealable can be sealed and gas-tight.

8 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

9 GRDC. (2016). Grain storage facilities: Planning for efficiency and quality. Stored grain hub. http://storedgrain.com.au/grain-storage-facilities/

Why do I need to do a pressure test?

In order to kill grain pests at all stages of their life cycle (egg, larvae, pupae, adult), phosphine gas concentration levels need to reach and remain at 300 parts per million (ppm) for seven days or 200ppm for 10 days.

Trials show that these levels of gas concentration are impossible to achieve in silos that are not pressure tested and gas-tight, so insects will not be killed at all life stages. The fumigation may appear successful when the adults die but the surviving eggs and pupae will continue to develop and reinfest the grain.

A pressure test is a measure of how well a silo will seal to contain fumigation gas.

When to perform a pressure test

If silos are properly maintained pressure testing does not take long and should be done at three distinct times.

1. When a new silo is erected on farm carry out a pressure test at a suitable time of day to make sure it's gas-tight before paying the invoice or filling with grain.
2. Importantly, a silo also needs to be pressure tested when full, before fumigating grain. If the silo has a slide plate outlet that has been tested empty, retest when full to make sure the pressure of the grain doesn't compromise the seal. The weight of grain can break the seal on the slide-plate outlet where it is not well supported by cams or bolts etc. For older, poorly-designed cone-bottom silos, gentle pressure from a jack may assist the seal. If the weight of grain on the slide plate stops it from sealing, some added pressure from a jack under the silo will assist the sealability.
3. Pressure testing silos needs to be part of the annual maintenance. It is much easier to replace seals and carry out repairs when silos are empty.

Carrying out a pressure test

4. Choose the right time to pressure test
5. Check seals
6. If there is no aeration fan, install an air valve
7. Check oil levels
8. Pressurise the silo
9. Time the half life
10. Look for leaks [10]

VIDEOS

WATCH: GCTV2 - Carrying out a pressure test

MORE INFORMATION

Pressure testing sealable silos

Sealed silos – take the pressure test

13.1.6 Grain bags

Key points:

- There are success stories with grain bags (known also as silo, sausage or harvest bags) when used to temporarily store grain, including pulses. There have also been failures when all appropriate precautions were not taken.
- Pulses are riskier than other grains to store in grain bags. Pulse grain has been rejected by markets because of objectionable taints and odours derived during improper storage in a grain bag.
- Grain bags are a sealed storage with no aeration. To maintain grain quality in storage it is essential to bag the grain at the correct moisture content and to ensure that the bag remains sealed through the entire storage period to prevent moisture ingress.
- High moisture grain, condensation, water aggregation under the film or through leaks can cause localised mould and wide-spread spoilage in pulses.
- Even with adequate seals, hermetic conditions (low O2, high CO_2) to protect against insects and mould are difficult to achieve consistently because of either high grain temperatures or low grain moisture content at the time of storage.

10 GRDC. (2014). Pressure testing sealable silos – Factsheet. http://storedgrain.com.au/pressure-testing/

Grain bags are becoming increasingly popular (Photo 2). It is important to appreciate their role and how they function, particularly when used to store pulses. [11]

Photo 2: *Temporary on-farm storage using reinforced plastic containers near Temora NSW.*

Photo: A Mostead, Source: GRDC

Grain bags allow for storage versatility, whether in the field where harvesting is taking place or at a grain storage site. They are large, sealed plastic bags that can temporarily store up to 300 tonnes of grain. They need to be completely sealed against the escape or entry of air, be impervious to outside interference or influence and an air tight seal must be maintained. As grain bags do not allow aeration, correct grain moisture content (below the current receival standard) at filling and maintenance of the air tight seal is vital. Birds, kangaroos, mice, and especially foxes have been known to penetrate them.

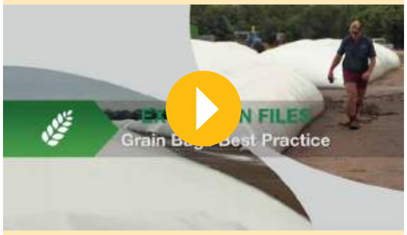
Grain bags are made from a laminated mix of up to three layers of polyethylene, with the first two layers acting as a UV filter and the third layer being darkened to keep out sunlight. Bags stretch up to 10% during the filling process. They are seamless, should be air tight when sealed and have a life of 12–18 months in the open. Ideally, they should prevent the development and reproduction of fungi and insects. Grain bags cannot be aerated, so the grain must be stored, and always kept, in sealed conditions. If hermetic conditions exist, the grain should turn residual oxygen into carbon dioxide to asphyxiate insects and inhibit fungi growth. CSIRO research has shown that this does not occur in practice though. A low-oxygen atmosphere is critical to successful insect and mould control, particularly at higher moisture contents and temperatures. Failure to seal punctures quickly and correctly will lead to failure. [12]

Grain bags for pulses

Pulses are one of the riskier grains to store in grain bags. Carefully assess the use of grain bags for pulses against the option of using other forms of storages for them and using the bags for another grain that is more appropriate (Table 3). If pulses are to be stored in grain bags, it should be considered as temporary only, and all precautions must be taken in terms of site selection, moisture content at filling, bag sealing, monitoring and maintenance. Consider using grain bags for treatment of a pulse grain sample that requires attention for it to make grade.

VIDEOS

WATCH: GCTV extension files: Grain bags—best practice



WATCH: GCTV extension files: Grain bags—a grower's perspective

MORE INFORMATION

Successful storage in grain bags

11 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

12 Pulse Australia. (2015). Australian Pulse Bulletin: Grain bags for pulse storage. http://www.pulseaus.com.au/growing-pulses/publications/grain-storage-bags

Table 3: *Advantages and disadvantages of grain bags for storing pulses.*

Advantages	Disadvantages
Grain bags are an effective short term (eg.3 months) storage option when used as a 'harvest buffer'.	There are disadvantages with grain bags, but as a short-term storage these can be managed.
Grain bags stored in the paddock where the crop is harvested reduce waiting time, transport costs and help avoid 'bottlenecks' with harvest and delivery.	Long-term costs can exceed that of permanent storages if grain bags are used each year as a routine storage practice.
They reduce dependence upon others during harvest and storage, enabling more efficient handling and turn around times.	Site selection, preparation, regular inspection and maintenance of the seal is absolutely critical for success.
Freight costs may be reduced at harvest and by negotiating rates outside peak harvest times.	Grain bags must be considered as short-term storage, and 'less desirable' for pulse grains
Minimal wastage or shrinkage loss if used correctly.	Bags are prone to damage by vermin, birds, pests and even native budworm larvae. Precautions need to be taken with regular inspections and repairs.
Allows additional, perhaps unlimited storage in a good season.	It cannot be assumed that grain bags provide hermetic conditions for storage, or that they always retain their air tight seal over time.
Grain can be segregated by variety, grade or any other reason	Discolouration, odours and deterioration of pulse grain quality can occur in storage in grain bags.
Quantity of grain stored can be varied by cutting the bag to the length required.	Grain moisture should be at or below the current receival limit for the grain type. This reduces risks from condensation and insects.
If stored correctly and short-term, the grain should retain its quality and colour.	Hermetic conditions are often claimed for insect and mould control. However, storage at high moisture and maintenance of grain quality are not necessarily being achieved with use of grain bags in Australia.
Chemical insect control may not be necessary, but only if the bag is sealed, maintained and remains air tight to provide continuous hermetic conditions.	Even with gas-tight seal, bagging dry grain leads to inadequate respiration to achieve the hermetic atmospheres required.
Grain producers are better able to control and time the marketing of the crop, which can lead to better prices being achieved.	Insects detected at outturn pose logistical problems that require permanent storage facilities to be available to turn and treat grain.
They can suit organic commodities	Pulse grain handled at low moisture content can lead to increased mechanical damage.
Grain stocks are visible and can be easily estimated for accounting purposes.	Grain bags require specialised filling and emptying equipment, and at peak use times sharing or hiring may become difficult.
Equipment used is transportable	Grain bags may require additional labour and a tractor at harvest.
Low cost per tonne of stored grain in the year of use.	Isolation of grain with localised spoilage on removal is difficult and impracticable where a bag extractor is used.

Advantages	Disadvantages
Using contractors and hire agencies avoids expenditure on purchasing your own equipment.	Physical bag life is 12–18 months and they cannot be reused as a grain bag.
Expenditure is minimised and only required in a season of big volume production rather than having capital tied up in permanent 'fixed' storage systems.	
Plastic from used grain bags can be used for other protective purposes eg. Hay stack covers.	

Source: Pulse Australia

Pulse quality risks

There are risks associated with storing pulses in grain bags:

- Pulse grain may not necessarily retain its quality, colour or odour, especially if the seal is breached.
- Contamination and moisture can enter bags from vermin and other pests that create holes in the bag. Pulses are more attractive than cereals to many vermin species, especially pigs which can easily damage silo bags.
- Excessive grain moisture can result in condensation within the bag causing localised areas of mould and objectionable odours.
- Pockets of mouldy grain can develop in grain bags, along with an offensive, distinctive 'mouldy' odour throughout. There is a nil tolerance of this by markets.
- Marketers have rejected pulse grain because of objectionable moulds, taints and odours acquired through storage in grain bags. Such taints and odours are not acceptable in pulse markets, particularly human consumption end-uses.
- Removing taints and odours in affected grain is often not possible, even with further aeration.
- Grain stored in grain bags can develop an overall offensive, distinctive 'plastic' odour that requires considerable periods of aeration to remove. There is nil tolerance of odours in receival standards.
- To achieve and maintain hermetic conditions under Australian conditions is difficult and should not be relied upon as the only source of storage insect control.
- Grain moisture content is critical. Pulses have bigger airspaces between grains than cereals, so moisture can move more freely through them. [13]

MORE INFORMATION

Grain bags for pulse storage

Successful storage in grain bags

13.2 Stored grain pests

Key points:

- The most common pulse pests are the cowpea weevil (*Callosobruchus* spp.).
- Only treat grain when insects are found. Grain markets have limitations on levels of chemical residues that must be adhered to. The demand for freedom from insecticide residues is increasing.
- The only control options are phosphine, an alternative fumigant or controlled atmosphere, all of which require a gas-tight, sealable storage to control the insects at all life stages.
- Chemical sprays are not registered for pulses in any State.
- Weevil development ceases at temperatures below 20°C. This is a strong incentive for aeration cooling, especially if gas-tight storage is not available. [14]

13 Pulse Australia. (2015). Australian Pulse Bulletin: Grain bags for pulse storage. http://www.pulseaus.com.au/growing-pulses/publications/grain-storage-bags

14 GRDC. (2016). Stored grain information hub: Storing pulses. http://storedgrain.com.au/storing-pulses/

- Lupin has good resistance to insect attack during storage.

The most common pest in lupins is the cowpea weevil (*Callosobruchus* spp.). The cowpea weevil has a short life span of 10–12 days. Though weevils are not usually a problem during short-term storage, they can damage grain that is cracked, has split seeds or has been damaged by seed borers. Rats and mice can also be a problem in lupin stored on-farm.

Weevil development ceases at temperatures below 20°C. This is a strong incentive for aeration cooling, especially if gas-tight storage is not available. [15]

Lupin seed stores much better than cereals and are more resistant to insect attack. This is one of the advantages of lupin grain, where if market prices are poor, they can be stored for a long period of time until prices increase again. This is common practice amongst growers in the Northern region.

Insect control options are limited for stored pulses and oilseeds. Grain protectants are not registered for use on these grains. Chemical sprays are not registered for pulses in any State. The only control options are phosphine, an alternative fumigant or controlled atmosphere, all of which require a gas-tight, sealable storage to control the insects at all life stages.

The effectiveness of phosphine fumigation on oilseeds can be reduced due to phosphine sorption during treatment. Use sound grain hygiene in combination with aeration cooling to reduce insect activity. Small-seed grains, may need larger capacity aeration fans on stores. Always store pulses at their recommended grain moisture content level. [16]

Grain markets demand that delivered grain is free of live insects. If insects are detected as grain is out-loaded for sale, treatment is likely to delay the delivery by 2–4 weeks. To maintain pest-free stored grain of good quality and value, growers need to:

- Make full use of good hygiene and aeration cooling – this can overcome 70% of pest problems.
- Identify pest incursions early through monthly monitoring (Figure 2). Early detection of pests gives the best chance of effectively treating the grain, preventing loss of grain quality and market access.
- Select the right storage treatments and apply them correctly.

The first grain harvested is often at the greatest risk of pest infestation due to contamination with grain left over from the previous season. It is good practice to separate the first few tonnes of grain that pass through headers and grain handling equipment at the start of harvest. Use it quickly for stock feed, or plan to aeration cool, then fumigate this grain within four weeks.

When it comes to controlling pests in stored grain — prevention is better than cure. Grain residues in storages or older grain stocks held over from last season provide ideal breeding sites.

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15 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

16 GRDC. (2016). Northern and Southern regions grains storage pest control guide. http://storedgrain.com.au/pest-control-guide-ns/

Figure 2: *Common stored grain pests.*

Source: Kondindin Group

MORE INFORMATION

Grain storage pest control options and storage systems.

13.2.1 Stored grain pest identification

The tolerance for live storage pests in grain either for domestic animal feed, human consumption or export markets is nil. Furthermore, an increasing number of grain markets are requesting low chemical residues on grain. It is important to accurately identify any pests to ensure use of the most appropriate control options. Correct identification and treatment choice helps prevent pest treatment failures due to chemical resistance. Follow the pest identification chart to work out which pest you have.

Keep a good magnifying glass handy to see the key features of these small insects. A piece of sticky tape may be helpful to hold insects still. To assist identification, place live insects into a glass container and check if they can climb up the glass. If it is cold, warm the jar in the sun briefly to encourage the insects to move.

The most common pest in lupins is the cowpea weevil (Bruchids).

Cowpea weevil or Bruchids

- Adults (up to 4 mm long) have long antennae, climb vertical surfaces (e.g. glass jar) and are strong flyers.
- Globular, tear-shaped body is reddish brown with black and grey markings (Photo 3).
- Does not have a long snout like true weevils.
- Adults have a short lifespan (10–12 days).
- Adults do not feed, but lay about 100 white eggs on the outside of seed.
- Larvae feed and develop within individual seeds and emerge as adults leaving a neat round hole.
- Common problem in warmer months.
- Fortnightly sampling and sieving is important to prevent serious losses. [17]

17 Plant health Australia. (2015). Monitoring stored grain on-farm. http://www.farmbiosecurity.com.au/wp-content/uploads/Monitoring-stored-grain-on-farm-2018.pdf

VIDEOS

WATCH: GCTV2: Grain storage insect ID

MORE INFORMATION

Identification of insect pests in stored grain

Stored grain pests identification: the back-pocket guide

Monitoring stored grain on-farm

Photo 3: *Adult Cowpea weevil and an example of infestation in seed.*

Source: DAFF Qld

Why identify stored insect grain pests?

Most insect-control methods for stored grain work against all species, so you don't need to identify the storage pests to make decisions about most control methods. But if you intend to spray grain with insecticides you may need to know which species are present if:

- A previous application has failed, and you want to know whether resistance was the reason—if more than one species survived, resistance is unlikely to be the cause.
- You intend to use a residual protectant to treat infested grain—pyrimiphos-methyl, fenitrothion and chlorpyrifos-methyl are ineffective against lesser grain borer, and pyrimiphos-methyl and fenitrothion are generally ineffective against saw-toothed grain beetles.
- You intend using dichlorvos to treat infested grain—if lesser grain borers are present you need to apply the higher dose rate, which increases the withholding period before grain can be marketed from seven days to 28 days. [18]

13.2.2 Hygiene

The first line of defence against grain pests is before the pulses enter storage — meticulous grain hygiene. Because pest control options are limited, it's critical to remove pests from the storage site before harvest.

18 DAFF. Identification of insects in stored grain. https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/grain-storage

Cleaning silos and storages thoroughly and removing spilt and leftover grain removes the feed source and harbour for insect pests.

Clean the following areas thoroughly:

- Empty silos and grain storages
- Augers and conveyers
- Harvesters
- Field and chaser bins
- Spilt grain around grain storages
- Leftover bags of grain [19]

When to clean

Straight after harvest is the best time to clean grain handling equipment and storages, before they become infested with pests. A trial carried out in Queensland revealed more than 1000 lesser grain borers in the first 40 litres of grain through a harvester at the start of harvest, which was considered reasonably clean at the end of the previous season. Discarding the first few bags of grain at the start of the next harvest is also a good idea. Further studies in Queensland revealed insects are least mobile during the colder months of the year. Cleaning around silos in July – August can reduce insect numbers before they become mobile.

How to clean

The better the cleaning job, the less chance of pests harbouring. The best ways to get rid of all grain residues use a combination of:

- Sweeping
- Vacuuming
- Compressed air
- Blow/vacuum guns
- Pressure washers
- Fire-fighting hoses

Using a broom or compressed air gets rid of most grain residues, a follow-up wash-down removes grain and dust left in crevices and hard-to-reach spots (Photo 4). Choose a warm, dry day to wash storages and equipment so it dries out quickly to prevent rusting. When inspecting empty storages, look for ways to make the structures easier to keep clean. Seal or fill any cracks and crevices to prevent grain lodging and insects harbouring. Bags of left-over grain lying around storages and in sheds create a perfect harbour and breeding ground for storage pests. After collecting spilt grain and residues, dispose of them well away from any grain storage areas. [20]

VIDEOS

WATCH: GCTV2: Grain Silo Hygiene.

Photo 4: *TIPS: An extended broom handle makes sweeping out silos easier (left). A concrete slab underneath silos makes cleaning easier. (right).*

Source: Kondinin Group

19 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

20 GRDC. (2013). Hygiene and structural treatments for grain storage – GRDC Factsheet. http://storedgrain.com.au/hygiene-structural-treatments/

13.2.3 Aeration cooling for pest control

While adult insects can still survive at low temperatures, most young storage pests stop developing at temperatures below 18–20°C (Table 4).

At temperatures below 15°C the common rice weevil stops developing.

At low temperatures insect pest life cycles (egg, larvae, pupae and adult) are lengthened from the typical four weeks at warm temperatures (30–35°C) to 12–17 weeks at cooler temperatures (20–23°C). [21]

Table 4: *The effect of grain temperature on insects and mould.*

Grain temp (°C)	Insect and mould development	Grain moisture content (%)
40–55	Seed damage occurs, reducing viability	–
30–40	Mould and insects are prolific	>18
25–30	Mould and insects are active	13–18
20–25	Mould development is limited	10–13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group

For more information on Aeration cooling, see Section 13.4.1 Aeration cooling below.

VIDEOS

WATCH: GCTV7: Applying Diatomaceous Earth demonstration

MORE INFORMATION

Hygiene and structural treatments for grain storage

13.2.4 Structural treatments

While most grain buyers accept small amounts of residue on cereal grains from chemical structural treatments, avoid using them or wash the storage out before storing oilseeds and pulses. After cleaning grain storages and handling equipment treat them with a structural treatment.

It is always safer to check with the grain buyer's delivery standards for maximum residue level (MRL) allowances before using grain protectants. Diatomaceous earth (DE) (amorphous silica), commonly known as Dryacide®, can be applied either as a dust or a slurry to treat storages and handling equipment for residual control. DE acts by absorbing the insect's cuticle (protective exterior), causing death by desiccation (drying out). If applied correctly with complete coverage in a dry environment, DE can provide up to 12 months protection — killing most species of grain insects and with no risk of building resistance. [22]

13.2.5 Chemical treatment

Key points:

- Chemicals used for structural treatments do not list the specific use before storing pulses on their labels and MRLs in pulses for those products are either extremely low or nil.
- Using chemicals even as structural treatments risks exceeding the MRL so is not recommended.
- Using diatomaceous earth (DE) as a structural treatment is possible but wash and dry the storage and equipment before using for pulses. This will ensure the DE doesn't discolour the grain surface.
- If unsure, check with the grain buyer before using any product that will come in contact with the stored grain. [23]

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21 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

22 GRDC. (2013). Hygiene and structural treatments for grain storage – GRDC Factsheet. http://storedgrain.com.au/hygiene-structural-treatments/

23 GRDC. (2016). Stored grain information hub: Storing pulses. http://storedgrain.com.au/storing-pulses/

Phosphine

In order to kill grain pests at all stages of their life cycle (egg, larva, pupa, adult), including pests with strong resistance, phosphine gas concentration levels need to reach and be maintained at 300 parts per million (ppm) for seven days (when grain is above 25°C) or 200ppm for 10 days (between 15–25°C).

Phosphine is available in two different forms for on-farm use (bag chains and tablets) and there are various ways to apply each option effectively in a gas-tight, sealed silo.

Bag chains are the safest form and the best way to guarantee no residue is spilt on the grain or will harm the operator. The other form is the traditional and most recognised — tablets — which can be bought in tins of 100. A third form — phosphine blankets — is available, but is designed for bulk storages larger than 600 tonnes.

Phosphine application rates are based on the internal volume of the gas-tight, sealable silo to be fumigated. Regardless of how much grain is in the silo whether it is full or empty, the rate is the same — based on the volume of the silo (Figure 3). [24]

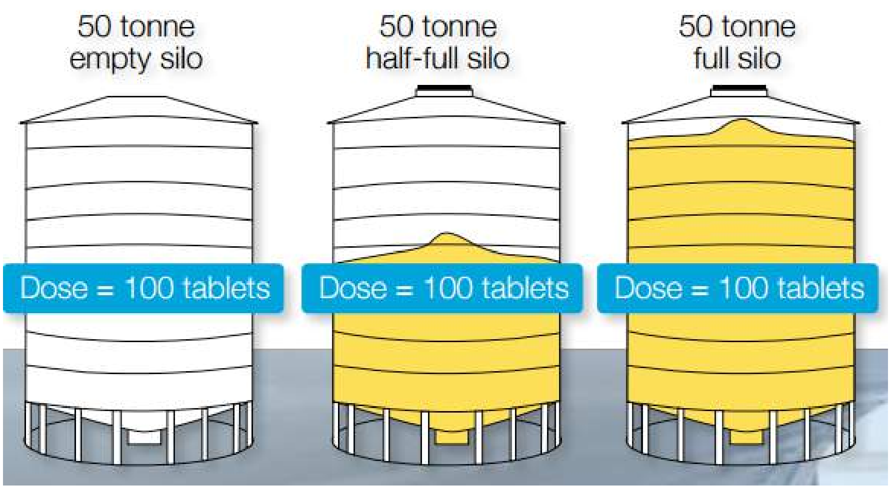


Figure 3: *Treat the silo volume, not the grain.*

Source: CBH

VIDEOS

WATCH: GCTV Stored Grain: Phosphine Dose Rates.

Using bag chains

The application rate for fumigating with a standard bag chain is one bag chain per 75m^3 or 60 t of wheat storage capacity. Always refer to the label. Do not cut a bag chain to save extra phosphine for use at a later date. The phosphine will start evolving as soon as it is exposed to air, so will be less effective if it's stored for use at a later date. Storing phosphine after it has already been opened also poses a danger when re-opened, as the gas has been dissipating in a confined space, potentially reaching explosive levels. For larger bulk storage silos, phosphine can be obtained in blanket form. Like bag chains, blankets must not be cut or separated so the minimum size storage for fumigation using a single blanket is 750m^3 or 600 t of wheat storage capacity.

Using tablets

The application rate for phosphine is 1.5 grams per cubic metre, which in tablet form equates to three tablets per 2m^3. Considering the typical bulk density of wheat is 1.3m^3/t the application rate is two tablets (2 g of phosphine) per tonne of storage capacity. Always read the product label to confirm recommended application rates.

24 GRDC. (2016). Fumigating with phosphine, other fumigants and controlled atmospheres. http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-PHOSP-Booklet_2016_R2_Reduced.pdf

Application from the top

Hang bag chains in the head space or roll out flat in the top of a gas-tight, sealed silo so air can freely pass around them as the gas dissipates. Always spread out phosphine tablets evenly on trays, before hanging them in the head space or placing them level on the grain surface inside a gas-tight, sealed silo. The aim is to place the tablets where as much surface area as possible is exposed to air so the gas can disperse freely. Prevent trays from sitting on an angle to avoid tablets piling up to one side and creating more than one layer in the tray.

Application from the bottom

Some silos are fitted with purpose-built facilities for applying phosphine from the bottom. This method of application carries a safety advantage as the operator doesn't have to leave the ground to apply the phosphine. However, ensuring top lids or vent openings on silos are in sound condition and correctly sealed before fumigation, will usually require a climb to the top. Bottom-application facilities must have a passive or active air circulation system to carry the phosphine gas out of the confined space as it evolves. Without air movement, phosphine can reach explosive levels if it's left to evolve in a confined space.

VIDEOS

WATCH: GCTV: Stored grain: Fumigation recirculation

Fumigation period

A gas-tight, sealed silo (one that satisfies a half-life pressure test) must remain sealed for the full 7–10 days to achieve a successful fumigation using phosphine tablets or bag-chains. In a gas-tight, sealed silo the required fumigation period is seven days if the grain temperature is above 25°C or 10 days if the grain temperature is between 15–25°C. If the temperature inside the silo is below 15°C, insect pests will not be active and phosphine is not reliably effective — avoid its use.

Opening the silo during fumigation is potentially harmful to the operator if they are not wearing the appropriate PPE, but also compromises the fumigation as gas concentration levels will quickly fall below the lethal level required to kill insect pests. Phosphine label recommendations have been developed as a result of thorough industry testing so using phosphine as the label specifies will achieve the best result.

Phosphine resistance

Poor fumigations may appear successful when some dead adults are found but many of the eggs, pupae and larvae are likely to survive and will continue to develop and reinfest the grain. These partial kills are often worse than no kill at all because the surviving insects, (adults, pupae, larvae and eggs) are likely to be those that carry increased phosphine resistance genes as a consequence. Underdosing risks increasing the number of insect populations carrying the genes for phosphine resistance and this has serious consequences for the industry.

Phosphine remains the single-most relied upon fumigant to control stored grain pests in Australian grain production systems, but continued misuse is resulting in poor insect control and developing resistance in key pest species. In the same way that repeated herbicide use of the same mode of action leads to resistant weeds, repeated phosphine use leads to resistant grain pests (Figure 4). Unlike herbicides, where resistance can be avoided by rotating chemical group from year to year, there are few alternative stored grain fumigation options other than phosphine. Alternative fumigants and controlled atmospheres that are available for stored grain pests are in most cases more expensive. The best way to prevent resistance is to use phosphine correctly — in a gas-tight, sealed silo.

MORE INFORMATION

[Fumigating with phosphine, other fumigants and controlled atmospheres]

[Grain fumigation – a guide.]

[Fumigation to control insects in stored grain]

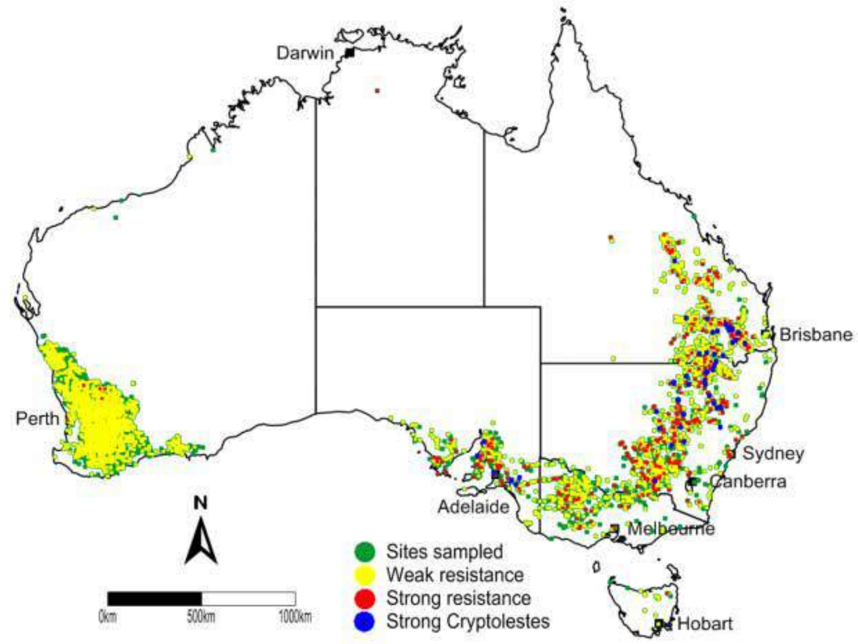


Figure 4: *Instances of phosphine resistance 1986 – 2014.*

Source: DAFWA

Phosphine safety

Caution should always be used when dealing with phosphine gas, it is not only toxic but also highly explosive. Observe all withholding periods for handling and grain use. Phosphine released from aluminium phosphide tablets, pellets or sachets has a characteristic smell which can usually be detected at concentrations within the safe level. Unless fumigating in a well-ventilated situation gas respirators suitable for protection against phosphine should be worn. Masks should fit properly for protection – this may be difficult for those with bearded faces – but is essential to avoid poisoning. Proper mask maintenance is also essential. For safety reasons, it is best not to work alone when applying phosphine tablets or in a structures that have been fumigated. Warning signs should be clearly displayed during fumigation. Always open containers of phosphine preparations in the open air or near open windows. If possible use the contents of a tin in one operation. If any is left over the tin lid should be replaced and sealed with PVC tape. [25]

Withholding period

After fumigating with phosphine, hold grain for a further two days after ventilation before delivering or using for human consumption or animal feed. This is a legal requirement as instructed by the label. The total time required for fumigation ranges from 10–17 days accounting for the minimum exposure period, ventilation and withholding period. It is important to monitor grain regularly and at least 17 days before out-loading to allow sufficient time for the fumigation process when required. [26]

Controlled atmospheres

Although phosphine is still the most commonly-used gas fumigant for controlling pests in stored grain, there are other options. Each of the alternatives still requires a gas-tight, sealable silo and are currently more expensive than using phosphine, but they offer an alternative for resistant pest species. Nitrogen and CO_2 carry the

25 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

26 GRDC. (2016). Fumigating with phosphine, other fumigants and controlled atmospheres. http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-PHOSP-Booklet_2016_R2_Reduced.pdf

advantage of being nonchemical control alternatives. Both nitrogen and CO_2 methods of control are sometimes referred to as controlled atmosphere (CA) because they change the balance of natural atmospheric gases to produce a toxic atmosphere.

Carbon dioxide

Treatment with CO_2 involves displacing the air inside a gas-tight silo with a concentration level of CO_2 high enough to be toxic to grain pests. This requires a gas-tight seal, measured by a half-life pressure-test of no less than five minutes. To achieve a complete kill of all the main grain pests at all life stages CO_2 must be retained at a minimum concentration of 35% for 15 days. The amount of CO_2 required to reach 35% concentration for 15 days is one 30 kg (size G) cylinder per 15 t of storage capacity, plus one extra cylinder. CO_2 is a non-flammable, colourless, odourless gas that is approximately 1.5 times heavier than air. Food grade CO_2 comes as a liquid in pressurized cylinders and changes to a gas when released from the cylinder.

The basic process is to open the storage's top lid to let oxygen out as CO_2 is introduced. Regulate the CO_2 gas into the bottom of the silo via a high pressure tube ideally 1 metre long (no longer than 2m). One kilogram of liquid CO_2 will produce approximately half a cubic metre of gas. Each cylinder could take three hours to dispense. In cooler conditions this process will take longer as the gas will tend to freeze if released from the bottle too quickly. This method of fumigation is not recommended when temperatures are below 15°C. Once the concentration at the top of the storage reaches 80%, stop adding CO_2 and seal the top lid.

Even in a silo that meets the five-minute, half-life pressure test, an initial CO_2 concentration of 80% or more is required to retain an atmosphere of 35% for the full 15 days, because the CO_2 is absorbed by the grain, reducing the atmospheric concentration over time. If the storage does leak, CO_2 can be added periodically over the 15 days if required. The key is to maintain the CO_2 concentration above 35% for 15 consecutive days, which will require suitable electronic instruments or a gas tube detector kit for monitoring. At temperatures below 20°C carbon dioxide is less effective because insects are less active so the concentration must be maintained for an extended period.

Nitrogen

Grain stored under nitrogen provides insect control and quality preservation without chemicals. It is safe to use, environmentally acceptable and the main operating cost is electricity. It also produces no residues so grains can be traded at any time, unlike chemical fumigants that have withholding periods. Insect control with nitrogen involves a process using Pressure Swinging Adsorption (PSA) technology, modifying the atmosphere within the grain storage to remove everything except nitrogen, starving the pests of oxygen.

The application technique is to purge the silo by blowing nitrogen-rich air into the base of the silo, forcing the existing, oxygen-rich atmosphere out the top. PSA takes several hours of operation to generate 99.5% pure nitrogen and before the exhaust air has a reduced concentration of two per cent oxygen. At 2% oxygen adult insects cannot survive, providing this concentration is maintained for 21 days with a grain temperature above 25°C. Anything less will not control all life stages — eggs, larvae and pupae. For grain below 25°C this period is extended to 28 days. The silo must be checked the day after fumigation and may need further purging to remove oxygen that has diffused from the grain. Nitrogen storage will also maintain the quality of canola and pulses by inhibiting the respiration process that causes oxidation, which leads to seed deterioration, increased free fatty acids and loss of colour. [27]

For further information on controlled atmosphere fumigation with CO_2 or nitrogen, contact the commercial suppliers of appropriate gas and equipment; BOC Gases Australia Ltd, on 13 12 62 or visit www.boc.com.au

27 GRDC. (2016). Fumigating with phosphine, other fumigants and controlled atmospheres. http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-PHOSP-Booklet_2016_R2_Reduced.pdf

13.2.6 Maximum Residue Limits

Key points:

- Grain samples are tested for pesticide residues in Australia and when export shipments leave the port to ensure they are within maximum residue limits (MRLs).
- A single violation of an importing country's MRL can lead to punitive measures on all Australian grain exported to that country and undermine Australian grains' reputation internationally.
- Consequences may include costs awarded against the exporter and/or grower. If repeated violations are detected with the same chemical, that chemical may be banned.
- It is essential that growers ensure both pre-harvest and post-harvest chemical applications adhere to the Australian Grain Industry Code of Practice.
- Use only registered products and observe all label recommendations including label rates and withholding periods.
- Trucks or augers that have been used to transport treated seed or fertiliser can be a source of contamination. Pay particular attention to storage and transport hygiene.
- Silos that have held treated fertiliser or pickled grain will have dust remnants that require particular attention. These silos either need to be cleaned or designated as non-food-grade storage.
- Compliance with Australian MRLs does not guarantee the grain will meet an importing country's MRL (which may be nil).
- Know the destination of your grain. When signing contracts, check the importing countries' MRLs to determine what pesticides are permitted on that crop.

By observing several precautions, growers can ensure that grain coming off their farm is compliant with the maximum pesticide residue limits that apply to Australian exports. Violations of maximum residue limits (MRLs) affect the marketability of Australian grain exports, and consequences may include costs being imposed on exporters and/or growers.

It is essential that both pre-harvest and post-harvest chemical applications adhere to the Australian Grain Industry Code of Practice, only registered products are used and all label recommendations, including rates and withholding periods, must be observed. Other key points include:

- Trucks or augers that have been used to transport treated seed or fertiliser can be a source of contamination – pay particular attention to storage and transport hygiene;
- Silos that have held treated fertiliser or pickled grain will have dust remnants – these silos either need to be cleaned or designated as non-food grade storage;
- Know the destination of your grain. When signing contracts, check the importing countries' MRLs to determine what pesticides are permitted on a particular crop. [28]

MORE INFORMATION

Managing MRLs factsheet

13.3 Aeration during storage

Aeration is important for high-moisture seed such as lupin seed, as it reduces temperature and provides a more uniform and stable storage temperature. Lower temperatures and aeration of silos reduce the chance of pest infestation of stored seed. Closed bulk storages can cause damage, as localised moisture leads to mould and patchy moisture damage. [29]

28 GRDC. (2014). Managing maximum residue limits in export grain - Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/07/grain-marketing-and-pesticide-residues

29 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

MORE INFORMATION

Aerating stored grain: cooling or drying for quality grain

Grain that is over the standard safe storage moisture level of 13% moisture content can be dealt with in a number of ways.

- Blending — over-moist grain is mixed with low-moisture grain then aerated.
- Aeration cooling — grain of moderate moisture (up to 13% moisture content) can be held for a short term under aeration cooling until drying equipment is available.
- Aeration drying — large volumes of air force a drying front through the grain in storage and slowly remove moisture. Supplementary heating can be added.
- Continuous flow drying — grain is transferred through a dryer, which uses a high volume of heated air to pass through the continual flow of grain.
- Batch drying — usually a transportable trailer drying 10–20 tonnes of grain at a time with a high volume of heated air to pass through the grain and out through perforated walls. [30]

Without aeration, grain is an effective insulator and will maintain its warm harvest temperature for a long time. Like housing insulation, grain holds many tiny pockets of air within a stack. [31]

Why aerate grain?

Aeration cools grain and slows most quality deterioration processes:

- Germination and seed vigour is maintained for longer when cool and dry.
- When grain temperatures are below 15–20°C grain storage pests´ life cycle slows or stops. Aeration can deliver these temperatures in winter and summer.
- Pulse grains maintain grain colour, reduce moulds risk.
- Mould development slows when grain moisture is uniform and below 13%.

Aeration capacity provides multiple benefits around harvest time:

- Ability to harvest early to reduce risk of weather damage causing quality and yield losses.
- Safely store grain at moisture levels a little above receival standards until blended with dryer grain.
- Hold high moisture grain safely for short periods prior to drying or blending.
- Return to harvesting earlier after rain delay.
- Gain extra harvesting hours each day. [32]

13.3.1 Aeration cooling

Key points:

- Grain temperatures below 20°C significantly reduce mould and insect development.
- Reducing grain temperature with aeration cooling protects seed viability.
- Controlling aeration cooling is a three-stage process — continual, rapid and then maintenance.
- Stop aeration if ambient, relative humidity exceeds 85%.
- Automatic grain aeration controllers that select optimum fan run times provide the most reliable results.

Aeration cooling:

- Creates uniform conditions throughout the grain bulk.
- Prevents moisture migration.
- Maintains seed viability (germination and vigour).
- Reduces mould growth.

30 GRDC. (2012). Grain storage factsheet: Storing Pulses.

31 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

32 DAFF Qld. (2010). Aeration for cooling and drying. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/grain-storage/aeration

- Lengthens (and in some instances stops) insect reproduction cycles.
- Slows seed coat darkening and quality loss.

Aeration cooling allows for longer-term storage of low-moisture grain by creating desirable conditions for the grain and undesirable conditions for mould and pests. Unlike aeration drying, aeration cooling can be achieved with air-flow rates of as little as 2–3 litres per second per tonne of grain. At this rate, aeration cooling can be delivered from fans driven by a 0.37 kilowatt (0.5 horsepower) electric motor for silos around 100 t.

High-moisture grain can also be safely held for a short time with aeration cooling before blending or drying. Run fans continuously to prevent self-heating and quality damage.

Be aware that small seeds will reduce the aeration fan capacity as there is less space for air to flow between the grains. [33]

Research carried out by the Department of Agriculture, Fisheries and Forestry (DAFF), Queensland shows that with the support of an aeration controller, aeration can rapidly reduce stored grain temperatures to a level that helps maintain grain quality and inhibits insect development.

During trials where grain was harvested at 30°C and 15.5% moisture, grain temperatures rose to 40°C within hours of being put into storage.

An aeration controller was used to rapidly cool grain to 20°C and then hold the grain between 17–24°C during November through to March.

Before replicating similar results on farm, growers need to:

- Know the capacity of their existing aeration system.
- Determine whether grain requires drying before cooling can be carried out.
- Understand the effects of relative humidity and temperature when aerating stored grain.
- Determine the target conditions for the stored grain. [34]

Air used for cooling grain

Varying ambient conditions affect stored grain differently depending on the combination of temperature and relative humidity outside the silo and the temperature and moisture content of the stored grain (Table 4).

Table 5: *The relationship between air temperature and relative humidity and grain moisture content*

Inlet Air		Resulting temperatures in wheat at varying moisture contents (°C)		
Temperature (°C)	RH (%)	10%MC	12%MC	14%MC
10°C	30	10.2	8.5	7.7
	60	14	11.6	10
20°C	30	18.7	16.1	14.2
	60	24.1	21	18.8
30°C	30	27.4	24.3	22
	60	34	30.4	27.9

Source: GRDC

Grain with a higher moisture content can be cooled quickly with low-humidity air due to the evaporative cooling effect that occurs inside the storage.

The relative humidity of the ambient air affects the efficiency of grain cooling.

VIDEOS

WATCH: Grain Storage cooling aeration.

33 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

34 GRDC Aeration cooling for pest contr30olcontrol. http://storedgrain.com.au/aeration-cooling/

In an ideal world, growers would select air for cooling that is low in temperature and relative humidity, but these conditions rarely occur.

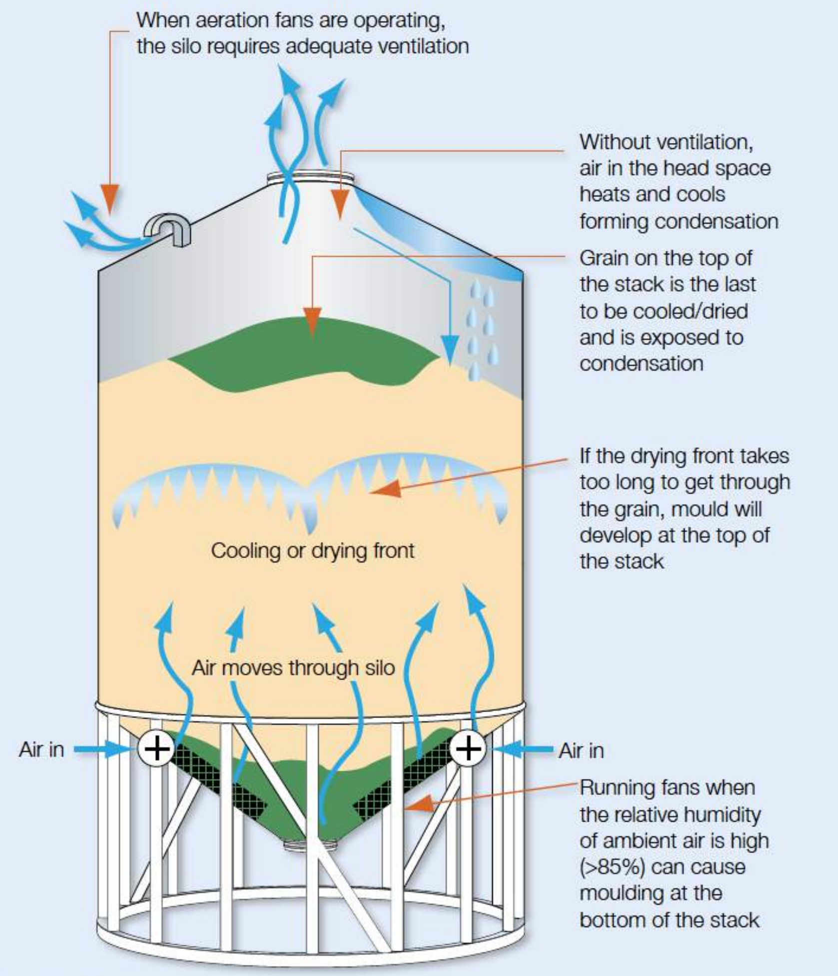
Air movement within the stack

Grain at the top of the stack is the hottest, as heat rises through the grain and it is exposed to the head space in the silo (Figure 5).

As the air in the head space heats and cools each day, it creates ideal conditions for condensation to form and wet the grain on the top of the stack.

Be aware aeration drying requires specifically-designed equipment and the process is much slower than aeration cooling or hot-air drying.

FIGURE 1 AIR MOVEMENT WITHIN AN AERATED SILO



Source: Kondinin Group

Figure 5: *Air movement within an aerated silo.*

Source: Kondinin Group

Operating an aeration fan for cooling requires a planned control program, which is best done with an automatic aeration controller. But even without an aeration controller growers need to aim for the same run time, following the same process.

For more information on automatic aeration controllers, see Section 13.3.4 Aeration controllers.

Without aeration, grain typically increases in temperature immediately after it enters the storage. The initial aim is to get maximum air-flow through the grain bulk as soon as it enters storage, to stop it from sweating and heating.

When first loading grain into storage, run the aeration fans continuously from the time the grain covers the aeration ducts for the next 1–3 days, until the cooling front reaches the top of the storage. However, do not operate the aeration fans on continuous mode if the ambient relative humidity is higher than 85% for extended periods of time as this will wet the grain.

After the aeration fans have been running continuously for 2–3 days to flush out any warm, humid air, reduce run time to 9–12 hours per day during the coolest period, for the next seven days. The goal is to quickly reduce the grain temperature from the mid 30s°C down to the low 20s°C.

An initial reduction in grain temperature of 10°C ensures grain is less prone to damage and insect attack, while further cooling becomes a more precise task. During this final stage, automated aeration controllers generally run fans during the coolest periods of the day, averaging 100 hours per month.

Grain temperature is gradually reduced as low as possible and then maintained throughout the storage period. [35]

The risks of getting it wrong

Running aeration fans on timers that are pre-set for the same time each day will not ensure the selection of the most appropriate air for grain quality maintenance.

The biggest risk with running aeration fans without a controller is forgetting or not being available to turn fans off if the relative humidity exceeds 85%.

Operating fans for extended periods of a few hours or days in humid conditions can increase grain moisture and cause moulding.

Aeration controllers are designed to automatically select the best time to run aeration fans. Fans on these systems only run when the conditions will benefit the stored grain.

13.3.2 Aeration drying

Grain growers are using silo aeration on their stored grain to gain harvest flexibility and more marketing options. Silo aeration can be used to cool grain and keep insect populations low. But it can also be used to dry the grain – allowing greater tolerance of moisture at harvest. Ambient air can also be used to dry grain. Here, high flow rates of air of at a temperature and humidity that will remove water from the grain (see grain equilibrium moistures) is pumped through the grain bulk.

Pulses stored for longer than three months at high moisture content (over 13%) will require drying or blending to maintain seed quality. Aeration drying has a lower risk of cracking and damaging pulses, which can occur with hot-air dryers.

Providing the air is of a quality that will dry and not re-wet the grain, the grain will dry from the bottom of the silo, with a drying front moving upwards through the grain stack. Aeration drying is a much slower process than aeration cooling or hot-air drying. The time it takes and the moisture content of grain after a drying front has reached the top of the grain stack is highly dependent on the quality of the air available and used for drying. Several drying fronts may be needed to dry grain to receival standards. If aeration is to be used for drying, check with your aeration supplier that the fan and ducting have sufficient flow rate and pressure to force a moisture change front through the grain in your silo quickly enough to prevent mould development. It is also critical to ensure that flow fields are even and grain depth is not too deep. Air with greatest capacity to dry, occurs most during the day when temperatures are high and relative humidity low, but this is not always the case. Very hot dry air can overdry and crack grain. The average quality of the inlet air (note fan heat effects) determines the final grain moisture content. [36]

35 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

36 GRDC. (2004). How aeration works. http://www.alliedgrainsystems.com.au/f.ashx/GrdcHowAerationWorks.pdf

VIDEOS

WATCH: GCTV5: Aeration drying – getting it right

MORE INFORMATION

How aeration works

Aerating stored grain – Cooling or drying for quality control.

Aeration cooling for pest control

Unlike aeration cooling, drying requires high airflow rates of at least 15–25 l/s/t and careful management. [37]

Well designed - purpose built high flow rate aeration drying silos with air flow rates of 15–20 l/s/t and higher, can dry grain from higher moisture contents, provided air of suitable relative humidity (RH) and temperature is available. Aeration drying requires careful management over several days and sometimes weeks depending on starting grain moisture and ambient conditions.

Note: It is vital to understand that aeration cooling equipment with low airflow rates of 2–4 l/s/t will not reliably dry grain and if used for this purpose, places the grain at significant risk.

For all aeration systems, provide adequate venting to ensure fan performance and air flow rates are not unnecessarily restricted. [38]

13.3.3 Cooling or drying — making a choice

Knowing whether grain needs to be dried or cooled can be confusing but there are some simple rules of thumb. For longer-term storage grain must be lowered to the correct moisture content.

Grain that is dry enough to meet specifications for sale can be cooled, without drying, to slow insect development and maintain quality.

Grain of moderate moisture can be either cooled for short periods to slow mould and insect development or, dried providing the right equipment and conditions are available.

After drying to the required moisture content, grain can be cooled to maintain quality. High-moisture grain will require immediate moisture reduction before cooling for maintenance. [39]

13.3.4 Aeration controllers

Running aeration fans on timers that are pre-set for the same time each day will not ensure the selection of the most appropriate air for grain quality maintenance. The biggest risk with running aeration fans without a controller is forgetting or not being available to turn fans off if the relative humidity exceeds 85%.

Operating fans for extended periods of a few hours or days in humid conditions can increase grain moisture and cause moulding. Aeration controllers are designed to automatically select the best time to run aeration fans (Photo 5). Fans on these systems only run when the conditions will benefit the stored grain. [40]

37 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

38 C Warrick. (2013). GRDC Factsheet: Aerating stored grain – Cooling or drying for quality control.

39 GRDC. (2016). Aeration cooling for pest control. Stored grain hub. http://storedgrain.com.au/aeration-cooling/

40 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

Photo 5: *Automatic aeration controllers are the most effective way to cool grain and are designed to manage many storages from one central control unit.*

Source: GRDC

Controllers for cooling

For the purposes of aeration cooling, automatic controllers are by far the most effective and most efficient method of control. Not only will they cool grain quickly and efficiently, they all have trigger points to turn fans off if ambient conditions exceed 85% relative humidity, which can wet grain. Automatic aeration controllers for cooling are available in four main variations:

- Set-point controllers
- Time Proportioning Controllers (TPCs)
- Adaptive Discounting Controllers (ADCs)
- Internal sensing controllers.

Controllers for drying

Most aeration controllers are now available with a drying function, which is generally performed using the manual, set-point method, the adaptive discounting method, or the internal sensing method of control. However, drying depends completely on the airflow through the grain and even with the addition of a drying function does not mean it will dry grain without appropriate quantity and quality of airflow. An aeration controller will greatly assist the drying process, but they are not a set-and-forget tool, as the grain requires regular monitoring and in most cases the controller requires regular adjustments.

Operating in drying mode, aeration controllers select for air with low relative humidity. They also provide the added benefit of ensuring fans are not left running when the ambient conditions exceed 85% relative humidity and grain could be re-wet. [41]

13.3.5 Installation and maintenance tips

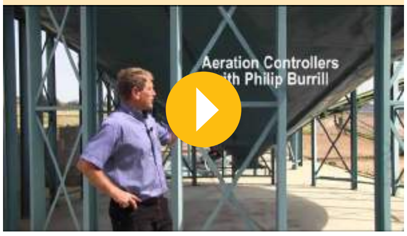
When retrofitting an aeration system, avoid splitting air-flow from one fan to more than one storage. Each storage will provide a different amount of back-pressure on the fan resulting in uneven air-flow and inefficient or even ineffective cooling.

If buying an aeration controller be aware that most controllers need to be installed by an electrician.

The preferred mounting location for aeration controllers is outside where the sensors can get ambient condition readings but are sheltered from the direct elements of the

VIDEOS

WATCH: Using aeration controllers – Philip Burrill.



41 C Warrick. (2013). GRDC Factsheet: Aerating stored grain – Cooling or drying for quality control.

weather. To avoid the chance of a dust explosion, avoid installing aeration controllers in a confined space.

Ensure your electrician installs wiring properly insulated and protected from potentially-damaging equipment, such as augers. [42]

13.3.6 Monitoring

Regular monitoring of stored grain is essential. Grain should be checked for, temperature, moisture content, quality, germination and for insect pests.

Aeration controllers reduce the amount of time operators need to physically monitor grain storages and turn fans on and off, but units and storage facilities still need to be checked regularly (Photo 6).

Most 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. Check fans to ensure they are connected and operating correctly. The smell of the air leaving the storage is one of the most reliable indicators if the system is working or not.

The exhausted air should change from a humid, warm smell to a fresh smell after the initial cooling front has passed through the grain. Animals can damage power leads and automatic controller sensors and fan blades or bearings can fail, so check these components regularly. Check for suction in and feel for air-flow out of the storage vents when the fans are running.

Keeping grain at the right moisture and temperature levels will reduce the likelihood of insect infestations, but stored grain still needs to be sampled regularly and monitored for any changes. If possible, safely check the moisture and temperature of the grain at the bottom and top of the stack regularly. [43]

Photo 6: *Monitor the effectiveness of the aeration cooling process by checking grain temperature with a temperature probe or a thermometer taped to a rod.*

Photo: Chris Warrick, Kondinin Group

42 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

43 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

13.3.7 Sampling grain for pests

Damage by grain insect pests often goes unnoticed until the grain is removed from the storage. Regular monitoring will help to ensure that grain quality is maintained.

Sample each grain storage at least monthly. During warmer periods of the year fortnightly sampling is recommended.

Take samples from the top and bottom of grain stores and sieve (using 2 mm mesh) onto a white tray to separate any insects (Photo 7).

Photo 7: *Use a 2 mm mesh sieve to separate insects from grain.*

Source: Kondinin Group

Hold tray in the sunlight for 10–20 seconds to trigger movement of any insects, making them easier to see. Use a magnifying glass to identify pests.

Grain probes or pitfall traps should also be used to check for insects. These traps are left in the grain during storage and are often able to detect the start of an infestation.

Push probe/trap into the grain surface and pull up for inspection fortnightly/monthly. Place 1–2 traps in the top of a silo or several traps in a grain shed (Photo 8).

Photo 8: *Probe traps pushed at the top of silos or bulk grain storages help detect the first signs of an insect infestation.*

Source: ProAdvice

MORE INFORMATION

Monitoring stored grain on-farm

Vigilant monitoring protects grain assets

Be sure to check grain three weeks prior to sale to allow time for treatment if required. [44]

Monitoring grain temperature and moisture content

Pests and grain moulds thrive in warm, moist conditions. Monitor grain moisture content and temperature to prevent storage problems. Use a grain temperature probe to check storage conditions and aeration performance. When checking grain, smell air at the top of storages for signs of high grain moisture or mould problems. Check germination and vigour of planting seed in storage. Aeration fans can be used to cool and dry grain to reduce storage environment problems. It is vital to monitor grain moisture content and temperature to prevent pests and grain moulds from thriving. [45]

13.4 Grain protectants for storage

There are no grain protectants registered for use in pulses in Australia.

44 Plant health Australia. (2015). Monitoring stored grain on-farm. http://www.farmbiosecurity.com.au/wp-content/uploads/Monitoring-stored-grain-on-farm-2018.pdf

45 Plant health Australia. (2015). Monitoring stored grain on-farm. http://www.farmbiosecurity.com.au/wp-content/uploads/Monitoring-stored-grain-on-farm-2018.pdf

Environmental issues

Key messages

- Though lupins can have good frost tolerance during the vegetative phase, the crop is susceptible to frost during the reproductive phase (which occurs once the plant initiates stem elongation).
- Knowing the frost risk in each paddock, altering sowing times and variety choice are the best ways to management for frost.
- Lupin is very susceptible to waterlogging.
- Reduce the impact of waterlogging through the choice of crop, seeding, fertiliser and weed control.
- Lupin is susceptible to drought and heat stress, especially later in crop development.
- Feral pigs can damage lupin and other pulse crops by consuming and trampling plants.

14.1 Frost issues for lupin

Key points:

- Frost is a relatively rare occurrence but some areas are more prone to it.
- There has been an increase in frost frequency in many areas in the last 20 years—and a decrease in other areas.
- Lupins are sensitive to frost, especially during the reproductive phase.
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect all the damage. [1]

Lupins prefer moderate temperatures and rainfall, they are not tolerant of frost and large losses of flowers can occur if frost is serve enough or ongoing (Photo 1). All current lupin varieties are susceptible to frost damage. Lupin has better frost tolerance than fieldpeas and chickpeas, but worse frost tolerance than faba beans. [2]

Photo 1: *Frost damaged lupin leaves.*

Source: GRDC

1 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

2 B Biddulph (2017) Frost and cropping. DAFWA. https://www.agric.wa.gov.au/frost/frost-and-cropping?page=0%2C0

14.1.1 Conditions that lead to frost

Clear, calm and dry nights following cold days are the precursor conditions for a radiation frost (or hoar frost). These conditions are most often met during winter and spring where high pressures follow a cold front, bringing cold air from the Southern Ocean and settled, cloudless weather (Figure 1). [3] When the loss of heat from the earth during the night decreases the temperature at ground level to zero, a frost occurs. Wind and cloud reduce the likelihood of frost by decreasing the loss of heat to the atmosphere. The extent of frost damage is determined by how quickly the temperature gets to zero, how long its stays below zero, and the how far below zero it falls.

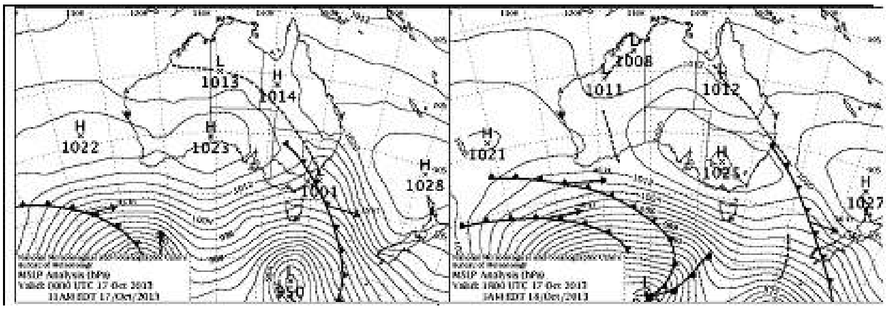


Figure 1: *A cold front passes through, injecting cold air in from the Southern Ocean the day before a frost (left). Overnight, the high-pressure system stabilises over south-east Australia, meaning clear skies and no wind leading to a frost event (right).*

Source: GRDC

Though temperatures (particularly in winter and spring) are getting warmer, frost is still a major issue, and likely to remain so. CSIRO researchers found that in some areas of Australia the number of frost events is increasing (with the greatest increase in August), and that central western NSW, the Eyre Peninsula, Esperance and the northern Victorian Mallee were the only major crop growing areas to be less affected by frost from 1961 to 2010 (Figure 2). [4] This increase is thought to be caused by the latitude of the subtropical ridge of high pressure drifting south (causing more stable pressure systems) and the existence of more El Niño conditions during this period. [5]

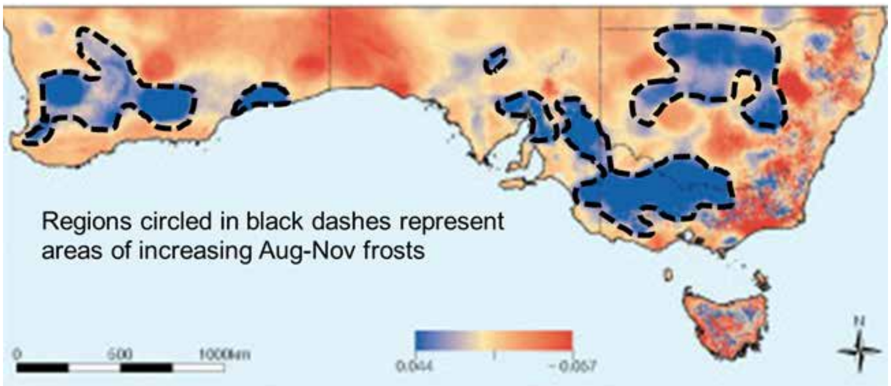


Figure 2: *Region of increasing August–November frost events.*

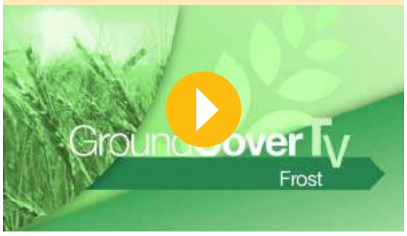
Source: GRDC

VIDEOS

WATCH: GCTV15: Frost ratings

WATCH: GCTV15: The frost ranking challenge

WATCH: GCTV12: Frost susceptibility ranked



3 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

4 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

5 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

14.1.2 Damage caused by frost

Though lupins can have good frost tolerance during the vegetative phase, the crop is susceptible to frost during the reproductive phase (which occurs once the plant initiates stem elongation). Low temperatures are more likely to occur in early spring during flowering and the early stages of pod development. These temperatures can cause abortion of small pods or failure of one or more seeds to develop within the pods. Extra seed production on the lateral branches may result. Though some compensation is possible (as the flowers do not develop at the same time as pods) lupins are generally unable to compensate for frost after flowering.

It is difficult to accurately assess the amount of frost damage in a crop because of its patchy nature and the difficulty in predicting compensation that may occur. To diagnose frost damage in pulse and canola crops, inspect between bud formation and during pod growth if night air temperature (recorded 1.2 m above ground) falls below 2°C and there was a frost. Check low-lying, light-coloured soil types and known frost-prone areas first. Then check other areas. Symptoms may not be obvious for five to seven days after the frost. [6]

What to look for in the paddock

- Low lying areas, light-coloured soil types, dry soil, and areas with more retained stubble are likely to be more damaged.

What to look for on the plant

- Plants with wilted upper foliage that shrivels and dies, or blistered pods.
- These frozen upper stems become discoloured (dark green directly after thawing) and associated foliage shrivels and dies (Photo 2.
- Often the damaged tissue (stem and pods) will take on a brown colour due to bacterial fungal infection (Photo 3)
- Stems have surface splits that turn brown with a mushy interior and can even lay over or twist from the damage
- Pods have pale surface spots or blisters and brown mushy lesions (Photo 4)
- Developing pods abort and fall off
- Developing seed may abort
- Unaffected parts of the plant grow, flower and set seed if there is sufficient time and soil moisture. [7]

6 B Biddulph (2016) Frost: Diagnosing the problem. DAFWA. https://www.agric.wa.gov.au/frost/frost-diagnosing-problem?nopaging=1

7 DAFWA (2017) Diagnosing frost in narrow-leafed lupins. https://www.agric.wa.gov.au/mycrop/diagnosing-frost-narrow-leafed-lupins

Photo 2: *Cracked, discoloured stems (left) with internal damage (right).*

Source: [DAFWA]

Photo 3: *Frosted lupin pods.*

Source: [DAFWA]

Photo 4: *Frosted lupin pods (left) and discoloured and malformed seeds (right) with brown mushy lesions on seed pods (right).*

Photo: Kathi Hertel, Source: NSW DPI (Left), DAFWA (right

Herbicides and frost damage

Frosts can affect herbicides in two main ways. Frosts can decrease the efficacy of the herbicide being applied since the frost is stressing not only the lupin plant, but also the weeds, impairing the weeds ability to take up the chemical. Group A products seem especially prone to this. The other effect of frost is to increase the incidence of crop damage from the herbicide. As mentioned, frosts stress plants, in this case lupins, and hinder the plants ability to metabolise the chemical. This risk is heightened when the safety margin of the chemical being used is low. Under these conditions, plants are more likely to be damaged (Photo 5). Droughted crops will be more sensitive to frosts and the associated herbicide damage as they are not as actively growing as those with adequate moisture levels.

Photo 5: *vDamage to lupin plants that were sprayed with Metrabuzin 24 hours prior to a frost event in NSW.*

Photo: D Pfeiffer

VIDEOS

WATCH: GCTV20: Frost's emotional impact—is it greater than its economic impact?

Growers are encouraged to study the weather forecast carefully before making a spraying decision. Look for weather conditions where there is no frost 2–3 days before the intended spray job and 2–3 days after.

Impact and cost of frost

The real cost of frost is a combination of the actual cost due to both reduced yield and quality, along with the hidden cost of managment tactics used to try and minimise frost risk. The hidden costs associated with conservative management to minimise frost risk includes:

- delayed sowing and its associated yield reduction
- sowing less profitable crops (i.e. tolerant crops) in an attempt to reduce the impacts of frost
- avoiding cropping on the valley floors which also contain some of the most productive parts of the landscape.

Frosts can also have quite a large social impact as it happens so suddenly, unlike drought which one can adapt to mentally and financially by reducing further inputs as it unfolds. [8]

14.1.3 Managing frost

Frost risk is difficult to manage in pulses, however some key management strategies may reduce the risk or extent of damage. These strategies include:

- Know the topography, and map areas of greatest risk so that they can be managed to minimise frost damage.
- Choosing the right crop type, crop variety and sowing time can help reduce exposure or impact at vulnerable growth stages.
- Carefully assess the soil type, condition and soil moisture levels, along with stubble and canopy management.
- Correct crop nutrition and minimised crop stress can influence the degree of frost damage.

Modifications to conditions over large areas are required to reduce frost risk. Small changes in management can have a big impact because frost damage occurs at specific 'trigger' temperatures. Keeping the air temperature even 0.1°C above the critical 'trigger' point will avoid frost damage. Air flow through the canopy can also have a positive impact towards avoiding frost damage. If the frost is severe, below the 'trigger temperature', damage occurs regardless of management, so then avoidance becomes important.

The soil is the heat bank, and it is desirable to have warm soil so that warm air can rise at night to minimize frost risk. The crop canopy will trap cold air on top, so a dense canopy is not necessarily desirable.

Problem areas and timings

Mapping or marking areas identified as frost-prone will enable growers to target frost and crop management strategies to these high-risk areas. Knowing when the period of greatest probability of frost risk occurs is also important for crop management. After a frost event, make note of the location and severity, as this will help to inform future crop choice and post frost decisions. Check low lying, light coloured soil types and known frost prone areas first.

Crop choice and time of sowing

Strategies to minimise frost damage in pulses work in combinations of either: growing a more tolerant species; trying to avoid having peak flowering and early podding during the period of most risk; extended flowering to compensate for losses to frost; or ensuring that most grain is sufficiently filled to avoid damage when frost occurs (Table 1). Time of flowering affects tolerance and the ability to compensate after the

8 B Biddulph (2017) Frost and cropping. DAFWA. https://www.agric.wa.gov.au/frost/frost-and-cropping?page=0%2C0

frost has occurred. Targeting flowering and early podding to periods of least frost risk (lowest probability) is achieved through combinations of sowing date and variety choice based on flowering time and flowering duration. Local experience will indicate the best choices.

Late flowering targets avoidance of early frosts, but in the absence of frost may also reduce yield potential due to moisture deficiency or high temperatures. Very early flowering can allow pods to be sufficiently developed to escape frost damage, and ensure some grain yield at least before a frost occurs. However, these pods can still be affected by stem damage; i.e. grain won't fill properly if stems are damaged. Increased disease risk needs to be considered with early sowing.

In southern NSW, frost damage risk can be reduced by not sowing varieties earlier than the recommended sowing window and so avoid flowering in July to early August. For most lupin-growing areas in southern NSW, sowing before late April increases the risk of frost damage with early flowering varieties such as Mandelup(D.

Table 1: *Lupin susceptibility to frost and risk exposure times.*

Frost tolerance of pods & seeds	Commencement of flowering	Length of flowering (duration)	Example variety	Frost tolerance or avoidance 'mechanism'
low–medium	very early–early	long	Mandelup(D, Wonga(D	Compensation with later podding
	late	short–medium	PBA Jurien(D, Jindalee(D, PBA Barlock(D	Avoidance (early frosts), some late podding compensation

Source: Pulse Australia

Plant growth after frost events

Well-developed pods will produce good quality seed, provided that mild, moist conditions follow the frost. Seed in less developed pods will shrivel and become brown in frosts. Lupin plants can compensate for frost damage by increasing the number of pods on the later-order laterals. In one study, although pod numbers were reduced by 40% on the main shoot and first-order laterals in a section of a crop affected by frost, there was a 100% increase in the numbers of pods on the basal, second- and third-order laterals. In addition, even though there can be up to 25% fewer seeds on the frosted plants, the seeds are heavier. [9]

Spread the risk

Match different pulses to risk areas by sowing a different variety or species into targeted areas within the same paddock. Matching the crop, variety, sowing date and subsequent inputs to the frost risk location spreads the risk.

Have forage as an optional use. Designating hay or forage as a possible optional use for the pulse in high frost-risk paddocks provides flexibility (Photo 6).

9 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Photo 6: *Frosted pulses make excellent quality forage.*

Source: Pulse Australia

Mixing two pulse varieties (long and short season, tall and short etc) balances frost risk with the risk of end of season drought, and reduces the risk of losses from any one frost event. Multiple frost events can damage both varieties. If grain from both varieties is not of the same delivery grade, then only the lowest grade is achieved. Flowering time differences are minimal in lentils and beans.

Sowing a mixture of pulse species is feasible, but not common. Complications in crop choice include achieving contrasting grain sizes, herbicide requirements, harvest timing and grain cleaning. Multiple frost events can occur that may damage both crops. Pulses grown in a mix will be suitable for feed markets only unless they can be cleaned to enable purity in segregation. If these difficulties can be overcome there is an opportunity for alternate-row sowing of different pulses.

Reduce frost damage

Minimise input costs to reduce financial risk exposure in frost-prone paddocks. Bear in mind though, that reducing inputs may reduce financial exposure and assist grain gross margins when crops are hit by frost, but can lessen the chance of a successful hay cut or jeopardise the crop if no frost occurs.

Manage nodulation and nutrition. Ensure pulse crops are adequately nodulated and fixing nitrogen. Ensure pulses have an adequate supply of trace elements and macro-nutrients – (supplying high levels is unlikely to increase frost tolerance). Crops deficient or marginal in potassium and copper are likely to be more susceptible to frost damage, and this may also be the case for molybdenum. Foliar application of copper, zinc or manganese may assist, but only if the crop is deficient in the element applied.

Canopy management. A bulky crop canopy, and exposure of the upper pods may increase frost damage. The pulse canopy can be managed. Semi-leafless, erect peas may be more vulnerable than conventional, lodging types because their pods are more exposed. A mix of two varieties of differing height, maturity and erectness may also assist in reducing frost damage.

Sow in wider rows, so that frost is allowed to get to ground level, and the inter-row soil is more exposed. An open canopy does not trap cold air. Wide rows require the soil to be moist to trap the heat in the soil during the day. With wide or paired rows and a wide gap, the heat can radiate up.

Channel cold air flow away from the susceptible crop by using wide rows aligned up and down the hill or slope. A sacrifice area may be required where the cold air settles.

Cereal stubble presence provides a cooler soil and root zone, worsening the frost effect compared with bare soil (Photo 7). Standing stubble is considered less harmful than slashed stubble as less light is reflected and the soil is more exposed to the sun. Dark coloured stubble will be more beneficial than light coloured.

Photo 7: *Lupin sown into cereal stubble.*

Source: DAFWA

Rolling can help keep soils warm by preventing soil moisture loss, but not necessarily on self-mulching or cracking soils. Note that press wheels roll only in the seed row, but not the inter-row. With no-till practice, avoid having bare, firm moist soil as it will lose some of its stored heat.

Claying or delving sandy soils increase the ability of the soil to absorb and hold heat by making the soil colour darker, and retaining moisture nearer the surface.

Higher carbohydrate level in the plant during frost leads to is less leakage during thawing. Biological farmers measure sugars in the plant sap ('Brix' reading). A higher sugar content (high Brix) will also have a lower freezing point, and associated protection against frost damage. The effectiveness of various products applied to soil and plant to increase plant carbohydrates is unknown.

Better varieties coming. The GRDC is investing through Pulse Breeding Australia in germplasm enhancement and pulse variety breeding for frost tolerance, including altered flowering time and duration to avoid frost; and screening of pulse varieties for relative levels of frost tolerance in the field. New varieties will be released when available. [10]

What to do with a frosted crop

There are a number of options to make use of a frosted crop, each with advantages and disadvantages (Table 2).

Table 2: *Management options for frost-damaged crops, with advantages and disadvantages.*

Options	Advantages	Disadvantages
Harvest	Salvage remaining grain More time for stubble to break down before sowing Machinery available	Cost may be greater than return Need to control weeds Threshing problems Removal of organic matter
Hay, silage	Stubble removed Additional weed control	Costs $35–50/t to make hay Quality may be poor Nutrient removal
Chain, rake	Retains some stubble (which reduces erosion risk) Allows better stubble handling	Raking costs $5/ha Time taken

10 Pulse Australia. (2015). Australian Pulse Bulletin. Minimising frost damage in pulses. http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

VIDEOS

WATCH: Frost initiative: Do micronutrients reduce frost risk?

WATCH: MPCN: Copper and frost relationship investigated

Options	Advantages	Disadvantages
Graze	Feed value	Inadequate stock to use feed Remaining grain may cause acidosis Stubble may be difficult to sow into
Spray	Stops weeds seeding Preserves feed quality for grazing Gives time for final decisions Retains feed Retains organic matter	With a thick crop, difficulty getting chemicals onto all of the weeds May not be as effective as burning Boom height limitation Costs $5/ha plus cost of herbicide Some grain still in crop
Plough	Recycles nutrients and retains organic matter Stops weed seedset Green manure effect	Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swathe	Stops weed seedset Windrow can be baled Regrowth can be grazed Weed regrowth can be sprayed	Relocation of nutrients to windrow Low market value for straw Poor weed control under windrow Costs to windrow Costs per herbicide to spray
Burn	Recycles some nutrients Controls surface weed seeds Permits re-cropping with disease control Can be done after rain	Potential soil and nutrient losses Fire hazard Organic matter loss

Source: GRDC

MORE INFORMATION

Tips and tactics: Managing frost risk

An analysis of frost impact plus guidelines to reduce frost risk and assess frost damage

Frost and cropping

Useful tools

There are numerous useful tools that can help growers decisions about aspects of cropping to maximise yields in frost-prone areas. Among them are:

- Bureau of Meteorology's BOM Weather app
- Plant development and yield apps—MyCrop and Flower Power (both from DAFWA), Yield Prophet
- Temperature monitors such as Tinytag

National Frost Initiative

Frost has been estimated to cost Australian growers around $360 million in direct and indirect yield losses every year. To help the grains industry minimise the damage frost causes, the GRDC has invested about $13.5 million in more than 60 frost-related projects since 1999. In 2014, it began the National Frost Initiative, to provide the Australian grains industry with targeted research, development and extension solutions to manage the impact of frost and maximise seasonal profit. [11]

The initiative is addressing frost management through multidisciplinary research projects in the following programs:

1. Genetics—developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.

11 T March, S Knights, B Biddulph, F Ogbonnaya, R Maccallum and R Belford (2015) The GRDC National Frost Initiative. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative

2. Management—developing best-practise strategies for crop canopy, stubble, nutrition and agronomic management so growers can minimise the effects of frost; and searching for innovative products that may minimise the impact of frost.
3. Environment—predicting the occurrence, severity and impact of frost events on crop yields and mapping frost events at the farm scale to enable better risk management. [12]

14.2 Waterlogging/flooding issues for this crop

Waterlogging occurs when there is insufficient oxygen in the soil pore space for plant roots to adequately respire. Waterlogging causes low soil oxygen concentrations, which limit root and shoot growth, function and survival. Root harming gases such as carbon dioxide and ethylene also accumulate in the root zone and affect the plants. Waterlogging symptoms include yellowing, stunting, or generally weak appearance and even death in the low-lying areas or patches (Photo 8).

Transient (hours to days) and longer term waterlogging (days to weeks) can cause substantial crop loss depending on the growth stage where waterlogging occurs. This problem occurs in low-lying areas in uneven fields either in irrigated lands or rainfed conditions during rainy season. Waterlogging can reduce root growth, and consequently reduce shoot extension and branching resulting in reduced plant biomass.

The risk of yield reduction and crop failure from waterlogging limit the range of soils where susceptible crops can be grown and even in better soils, that do not suffer prolonged waterlogging, short periods of transient waterlogging can have devastating effects when waterlogging occurs during reproductive growth.

Photo 8: *A patch in a pulse crop that is damaged and dying due to prolonged waterlogging.*

Photo: David Jochinke

Lupin is more sensitive than other pulse crops to waterlogging, and albus lupin is more sensitive than narrow-leafed lupin. Lupin will not germinate in waterlogged soils, and seed survival may be reduced to zero after as few as 4 days. Waterlogged soils also severely restrict the growth of the main and secondary root systems. Soil moisture at 50% of field capacity gives the best main root growth at establishment.

VIDEOS

WATCH: GCTV3: Frost R&D

WATCH: GCTV16: National Frost Initiative

MORE INFORMATION

Managing frost risk: northern, southern and western regions

12 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, www.grdc.com.au/ManagingFrostRisk

In general, young vegetative plants (28 to 42 days after sowing) are more sensitive to waterlogging than are plants during reproductive development (56 to 70 days after sowing).

Nitrogen fixation needs large amounts of oxygen. Short periods of waterlogging can also reduce nodulation and cause nitrogen deficiency. Prolonged conditions of low oxygen, as occur during waterlogging, will cause nodules to stop functioning and die. [13]

Waterlogging in lupin crops can also increase the risk of disease. For example, Phytophthora root rot develops following a period of waterlogging (as short as 8 hours) in winter which allows the Phytophthora pathogen to infect lupin roots, and is expressed in spring when plants prematurely die often around pod filling. Occurrence of the disease is associated with soils prone to waterlogging, low lying paddocks and hardpans (which can develop perched water tables). The disease can occur on individual plants up to large patches within a crop. [14]

For more information on Phytopthora root rot, see Section 9: Diseases.

14.2.1 Hardpans and waterlogging in southern NSW

Many pulse crops in southern NSW and northern Victoria had symptoms of waterlogging in 2016. Throughout spring, many plant samples were received at the diagnostic laboratory at Wagga Wagga with evidence of waterlogging, leading to premature death.

Waterlogging can have a three stage effect on pulse crops. Firstly, plants standing in free water can effectively 'drown' if the waterlogged conditions occur over an extended period and the pulse crop will die prematurely. Secondly, waterlogged conditions can promote root pathogens to infect and cause injury, such as Phytophthora, which are expressed later in the season. Thirdly, observations in northern NSW pulse trials and crops since 2010 have consistently shown that resistance to foliar disease is reduced if plants are waterlogged.

Hardpans (or ploughpans) can lead to waterlogging issues, in particular the development of perched watertables in the root zone. Hardpans often form just below the depth of cultivation. This can result in root disease development, poor nodulation or poor root growth. In the 1990s, a survey of pulse crops in southern NSW found 50% of paddocks to have soil bulk densities high enough to limit water movement and root development in pulse crops.

Check paddocks to be sown to pulses for hardpan layers. It may be necessary to cultivate paddocks at a deeper level or use ripping tynes to break up layers. [15]

14.2.2 Symptoms of waterlogging

What to look for in the paddock

- Poor germination or yellow plants, in water collecting areas, particularly on shallow duplex soils (Photo 9).
- Bare wet soil and/or water-loving weeds present.
- Plants in waterlogged areas may prematurely die.
- Saline areas are more affected.

13 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

14 K Lindbeck (2017) GRDC Update Papers: The watch outs for pulse disease in 2017. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/02/the-watch-outs-for-pulse-diseases-in-2017

15 K Lindbeck (2017) GRDC Update Papers: The watch outs for pulse disease in 2017. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/02/the-watch-outs-for-pulse-diseases-in-2017

Photo 9: *Poor germination or smaller yellow plants can be seen in areas where waterlogging occurs.*

Source: DAFWA

What to look for in the plant

- Waterlogged seedlings can die before emergence.
- Smaller pale plants with pale to bright orange-yellow leaflets on older leaves that are shed.
- Plants gradually die if waterlogging persists, or appear to recover then die prematurely in spring because damaged root systems cannot access subsoil moisture.
- Nodulation failure with poor nodulation, small, pale nodules or nodules may die with extended waterlogging (Photo 10).
- Waterlogged roots initially have reduced growth then turn brown and die. The plant often compensates with new roots emerging from the hypocotyl
- Plants are more susceptible to root and foliar diseases, and may be more affected by aphids.
- Salinity magnifies waterlogging effects, with more marked stunting and leaflets on oldest leaf tip dying back from the tip. [16]

16 DAFWA (2015) Diagnosing waterlogging in narrow-leafed lupins and field peas. https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-narrow-leafed-lupins-and-field-peas

Photo 10: *Plants are often pale with thinner stems and poor nodulation, reduced taproot and brownish roots (left). Loate-onset waterlogged plants have orange-yellow colouring in older leaves (right).*

Source: DAFWA

Monitoring

Key points:

- Plants can be waterlogged when there is a watertable within 30 cm of the surface and no indication of waterlogging at the surface. Water levels can be monitored with bores or observation pits, but watertables can vary greatly over short distances.
- Observe plant symptoms and paddock clues and verify by digging a hole.
- The salinity status of a soil can be assessed from indicator plants, measuring the salt concentration in soil samples or with electromagnetic-induction instruments, or by measuring the depth to a saline watertable.

How can waterlogging be monitored?

Waterlogging occurs:

- Where water accumulates in poorly drained areas such as valleys, at the change of slope or below rocks.
- In duplex soils, particularly sandy duplexes with less than 30 cm sand over clay.
- In deeper-sown crops.
- in crops with low levels of nitrogen.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [17]

As well, waterlogging greatly increases crop damage from salinity. Germination and early growth can be much worse on marginally saline areas after waterlogging events.

Identifying problem areas

- Water levels can be monitored with bores or observation pits, but water tables can vary greatly over short distances so siting needs to be done care.
- Plants can be waterlogged if there is a water table within 30 cm of the surface. There may be no indication at the surface that water is lying in the root zone. Observe plant symptoms and paddock clues, and verify by digging a hole to test for water seepage. [18]

17 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

18 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

The best way to identify problem areas is to dig holes about 40 cm deep in winter, and see if water seeps or flows into them (Photo 11). If it does, the soil is waterlogged. Some farmers put slotted PVC pipe into augered holes. They can then monitor the water levels in their paddocks. Digging holes for fence posts often reveals waterlogging.

Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- The presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [19]

Photo 11: *Water fills a hole that has been dug in waterlogged soil.*

Source: Soilquality

Other impacts of waterlogging and floods

Heat from stagnant water

Stagnant water, particularly if it is shallow, can heat up in hot, sunny weather and may kill plants in a few hours. Remove excess water as soon as possible after flooding to give plants the best chance of survival.

Chemical and biological contaminants

Floodwater may carry contaminants, particularly from off-farm run-off. You should discard all produce, particularly leafy crops, that have been exposed to run-off from beyond the farm.

Make sure you take food-safety precautions, and test soils before replanting, even if crops look healthy. Contaminants will reduce over time with follow-up rainfall and sunny weather.

Iron chlorosis or nitrogen deficiency

Floods and high rainfall can leach essential nutrients from the soil, which can affect plant health. Nutrients such as iron and nitrogen can be replaced by fertilising.

19 Soilquality (2016) Waterlogging. Fact sheet. Soilquality, http://soilquality.org.au/factsheets/waterlogging

VIDEOS

WATCH: GCTV3: Big wet—management strategies after flooding

Soils with high clay content

Soils with a high clay content can become compacted and form a crust after heavy rain and flooding. Floodwater also deposits a fine clay layer or crust on top of the soil, and this can prevent oxygen penetrating into the soil (aeration). Clay layers should be broken up and incorporated into the soil profile as soon as possible.

Pests and diseases

Many diseases are more active in wet, humid conditions, and pests can also cause problems. Remove dying or dead plants that may become an entry point for disease organisms or insect pests. Apply suitable disease-control measures as soon as possible, and monitor for pests. [20]

14.2.3 Managing waterlogging

Key points:

- Reduce the impact of waterlogging through the choice of crop, seeding, fertiliser and weed control.
- Avoid growing narrow-leafed lupins on regularly waterlogged soils. In the case for lupins these areas often provide focal points for bean yellow mosaic virus infection and diseases such as sclerotinia and brown spot.
- Sow waterlogging-tolerant crops such as oats and faba beans.
- Sow as early as possible with a higher seeding rate.
- Drainage may be appropriate on sandy duplex soils on sloping sites.
- For paddocks susceptible to waterlogging, plant them first with the best crop choice for vigorous early growth.
- Raised beds are more effective on relatively flat areas and on heavier textured soils, but areas need to be large enough to justify machinery costs.
- Carry out farming practices that reduce compaction e.g. tram tracking and zero till

Drainage is usually the best way of reducing waterlogging. Drain waterlogged soils as quickly as possible, and cultivate between rows to aerate the soil.

Good drainage is essential for maintaining crop health. Wet weather provides a good opportunity to improve the drainage of your crop land, as it allows you to identify and address problem areas.

There are several things you can do to improve crop drainage, immediately and in the longer term.

Drainage problems after flooding

After significant rain or flooding, inspect the crops when it is safe to do so and mark areas (e.g. with coloured pegs) that are affected by poor drainage. If possible, take immediate steps (e.g. by digging drains) to improve the drainage of these areas so that the water can get away.

Irrigation after waterlogging

To avoid recurrence of waterlogging, time irrigation by applying small amounts often until the crop's root system has recovered.

Ways to improve drainage

In the longer term, look for ways to improve the drainage of the affected areas. Options include:

- reshaping the layout of the field
- improving surface drainage

20 Queensland Government Business and Industry Portal (2016). Managing risks to waterlogged crops. Queensland Government, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/managing-risks-waterlogged-crops

MORE INFORMATION

[Cropping on raised beds in southern NSW]

[Nitrogen management in waterlogged crops]

[Should waterlogged crops be topdressed with N fertiliser?]

- installing subsurface drainage

If the drainage can't be improved, consider using the area for some other purpose (e.g. as a silt trap). [21]

Choice of crop species

Some species of grains crop are more tolerant to waterlogging and being flooded than others. Grain legumes and canola are generally more susceptible to waterlogging than cereals and faba beans.

Seeding crops early and using long-season varieties help to avoid crop damage from waterlogging. Damage will be particularly severe if plants are waterlogged between germination and emergence. Plant first those paddocks that are susceptible to waterlogging. However, if waterlogging delays emergence and reduces plant density to fewer than 50 plants/m^2, resow the crop.

Seeding rates

Increase sowing rates in areas susceptible to waterlogging to give some insurance against uneven germination. High sowing rates will also increase the competitiveness of the crop against weeds, which take advantage of stressed crops. Seeding crops early and using long-season varieties help to avoid crop damage from waterlogging. Crop damage is particularly severe if plants are waterlogged between germination and emergence. Plant first those paddocks that are susceptible to waterlogging.

Nitrogen fertiliser

Crops tolerate waterlogging better if they previously had a good nitrogen level. Applying nitrogen at the end of a waterlogging period can be an advantage if nitrogen was applied at or shortly after seeding because it avoids loss by leaching or denitrification. However, as nitrogen cannot usually be applied from vehicles when soils are wet, consider aerial applications.

If waterlogging has been moderate (7–30 days waterlogging of the soil), fertiliser application after waterlogging, when the crop is actively growing again, is on recommendation. However, if waterlogging has been severe (greater than 30 days to the soil surface), the benefits of fertiliser application after waterlogging are questionable.

Weed density affects the ability of a crop to recover from waterlogging. Weeds compete for water and the small amount of remaining nitrogen, hence the waterlogged parts of a paddock are often weedy and require special attention if the yield potential is to be reached. If herbicide resistance is not a problem, spray the weedy areas with a post-emergent herbicide when the paddock is dry enough to allow access, provided the crop is at an appropriate growth stage. Aerial spraying is an alternative when ground-based sprays cannot be used. [22]

Raised beds

Raised beds are the only long-term option for preventing waterlogging and increasing crop yield on target areas (Photo 12). Crop yields are more reliable and yield and profit are increased.

21 Queensland Government Business and Industry Portal (2016) Improving drainage of crop land. Queensland Government, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/improving-drainage-crop-land

22 DAFWA (2015) Management to reduce the impact of waterlogging in crops. DAFWA, https://www.agric.wa.gov.au/waterlogging/management-reduce-impact-waterlogging-crops

Photo 12: *Waterlogged crop without raised beds (left) while the crop on raised beds remains healthy (right).*

Source: DAFWA

Raised beds are an option when:

- High rainfall areas
- The probability of waterlogging is 50% or more in the wettest months (usually June to August) when the emerging crops are most susceptible and on susceptible soils.
- Shallow water tables and large gravel contents in the soil reduce the soil's capacity to absorb rainfall, resulting in a high frequency of waterlogging.
- Where hill slopes are greater than 3%, waterlogging may not be a problem. In shallow or gravelly soils, however, waterlogging can occur on land with slopes greater than 3%.

Susceptible soils are:

- Shallow sand, high gravel content soils and loam-over-clay soils situated in areas where the waterlogging frequency is greater than 50%.
- Soils in areas with a shallow water table will also be susceptible but that land is likely to be salt-affected and reclamation of the salinity is likely to be difficult, even with the use of raised beds.

Raised beds may be an option in many situations and professional advice should be obtained before installing them. [23]

MORE INFORMATION

Cropping on raised beds in southern NSW

Raised bed cropping

Innovative management techniques to reduce waterlogging

14.3 Other environmental issues

For information on salinity, sodicity and other soil constraints, see Section 1: Planning and Paddock preparation.

14.3.1 Drought stress

Key points:

- Drought stress is a key yield-limiting factor in crop production.

Drought is one of the major environmental factors that reduces grain production in the rain-fed and semi-arid regions of Australia (Photo 13).

23 D Bakker. (2015). Raised beds to alleviate waterlogging. https://www.agric.wa.gov.au/waterlogging/raised-beds-alleviate-waterlogging

Photo 13: *Drought conditions in 2015 left a dry landscape prone to dust storms.*

Photo: Brad Collis, Source: GRDC

Understanding of lupin responses to drought is limited. There have been mixed reviews on the ability of lupin to tolerate drought stress.

Influence of drought on lupin

Spring drought

Spring drought refers to plant water stress from insufficient rainfall or stored soil moisture from bud formation to maturity.

Crop growth in lupin under pre-anthesis water shortage (i.e. drought conditions) is reduced mainly through an adjustment in leaf area by abscission (leaf drop) of fully expanded leaves from the mid to lower canopy, and a reduction in leaf expansion of newly formed leaves

Reductions in crop growth caused by pre-anthesis drought spells may affect grain yield by reducing nitrogen fixation, limiting biomass, and the capacity to fill pods on the mainstem and develop apical branches. In most indeterminate grain legumes, like lupin, nitrogen accumulation at anthesis is strongly correlated with grain number per unit area, the main determinant of grain yield. [24]

Terminal drought

Lupin is also sensitive to end-of-season drought and terminal drought, which are common features of the lupin cropping regions of Australia. Terminal drought develops when rainfall decreases and evaporation and temperature increase in the spring, when lupin enters its reproductive stage. [25] Compared with cereals, pulses, and some oilseed crops the grain yield of lupin is more severely affected by terminal drought. The comparison of the yield performance under terminal drought and well-watered treatments showed that while the grain yield of cereals, pulses, and some oilseed crops was reduced by 39.7–53.8 % the grain yield of lupin was reduced by 60–93.8 %. [26]

Yield under terminal drought is often reduced through pod and seed abortion. Varietal selection has ensured early flowering in narrow-leafed lupin, providing more

24 J Palto, J Berger, H Bramley (2012) Chapter 16 – Physiology of yield under Drought: Lessons from studies with Lupin. In Aroca, R. (2012). Plant responses to drought stress. In *From Morphological to Molecular Features*. Springer-Verlag GmbH Berlin Heidelberg.

25 Palta J.A., Berger J.D. and Ludwig C. 2008. The growth and yield of narrow leafed lupin: myths and realities. 12th International Lupin Conference, Canterbury, New Zealand, 1, pp. 20–25.

26 J Palto, J Berger, H Bramley (2012) Chapter 16 – Physiology of yield under Drought: Lessons from studies with Lupin. In Aroca, R. (2012). Plant responses to drought stress. In *From Morphological to Molecular Features*. Springer-Verlag GmbH Berlin Heidelberg.

time for pod filling before the severe effects of drought on carbon assimilation occur. The ability to avoid yield loss under terminal drought conditions is characteristic of modern narrow-leafed lupin cultivars such as Belara, Quinilock and Mandelup(), with early flowering and podding and higher rates of seed-filling than in other cultivars.

There is speculation that terminal drought escape may limit yield improvement. Finishing the growing season early limits the time available for accumulating biomass, generating a tension between drought escape and maximising source potential. [27]

Water use

Lupins appear to have a mix of competitive and conservative water use strategies. It is considered to be a profligate water user when water is freely available, a competitive strategy that facilitates water capture before it is lost to drainage, or is taken up by neighboring plants. Conversely, narrow-leafed lupin is very sensitive to drying soils, reducing stomatal conductance well before changes in leaf water potential; [28] a strategy that is likely to conserve water when soil water content is relatively low, and drainage unlikely to be an issue. It may be that this mix of water use strategies is the ideal adaptation of lupin to sandy soils. Deep sandy soils have with limited water-holding capacity allowing lupin crops to profligate when there is a high risk of losing water to drainage, and to be conservative when there is not. These strategies contrast with cereal crops such as wheat that are more tolerant to terminal drought under the same field conditions.

Relative to wheat, lupin has an area-based photosynthetic rate that is 80% higher than that of wheat when soil water is adequate. At flowering of both lupin and wheat, canopy photosynthesis in lupin is higher than in wheat. However, the rate of net photosynthesis in lupin is more sensitive to water deficits than the rate of net photosynthesis in wheat. [29]

IN FOCUS

Soil-plant water relations, root distribution and biomass partitioning in narrow-leaf lupins under drought conditions

Narrow-leaf lupin varieties from different climatic origins responded to a 15 day period of water shortage during flowering by losing 50% of the total leaf canopy and gaining 55% in stem dry weight. Water deficits also led to a significant increase in the fine root length density and a slight increase in the fine root dry weight. The latter increase was especially pronounced in the deeper soil layers. Some marginal differences among genotypes were observed in the responses. Stomatal closure by midday was an early response to water deficit, giving rise to constant predawn leaf water potentials during the first week of water shortage in spite of a decrease of 60% in the available soil water. No osmotic regulation or adjustments of the cell wall properties were observed in any of the lupin lines. The seed production in water-stressed plants was upheld by their ability to accumulate assimilates in the shoot, which would be diverted to the pods during the seed filling stage. [30]

27 Redden, R., Palta-Paz, J., Atkins, C., Gready, J. E., Dwyer, S. A., & Evans, J. R. (2013). Legume productivity and photosynthetic responses anticipated with climate change: insights from lupins. *Applying photosynthesis research to improvement of food crops*, 61.

28 Turner NC, Henson IE (1989) Comparative water relations and gas-exchange of wheat and lupins in the field. In: Kreeb KH, Richter H, Hinckley TM (eds) Structural and functional responses to environmental stresses: water shortage. SPB Academic Publishing, The Hague, pp 293–304

29 J Palto, J Berger, H Bramley (2012) Chapter 16 – Physiology of yield under Drought: Lessons from studies with Lupin. In Aroca, R. (2012). Plant responses to drought stress. In *From Morphological to Molecular Features*. Springer-Verlag GmbH Berlin Heidelberg.

30 Rodrigues, M. L., Pacheco, C. M. A., & Chaves, M. M. (1995). Soil-plant water relations, root distribution and biomass partitioning in Lupinus albus L. under drought conditions. *Journal of Experimental Botany*, *46*(8), 947–956.

Symptoms of drought

What to look for in the paddock:

- Large areas of stressed or dying plants with some better plants in water-gaining areas (Photo 14). Areas most affected include:
- Low water holding soils, such as coarse sands and gravels, very shallow soil over rock or impermeable layer.
- Heavy clays that retain moisture near the soil surface after light rainfall where it is more liable to evaporate.
- Areas within the root zone of trees.
- Double sown areas and more vigourous plants.
- areas where summer weeds have got away and the starting moisture was lower than the rest of the paddock
- Compacted areas

Photo 14: *Drought affected lupins in NSW.*

Photo: P Heuston

What to look for in the plant:

- During the vegetative stage leaves turn dark green to purple and tend to stand upright. Older leaves turn yellow and die.
- During flowering, flowers are aborted, pod set is significantly reduced and plants are stunted and wilt and can ultimately die (Photo 15).
- Pod length is reduced and seed development is affected, resulting in shrivelled seed, which may also remain green if the moisture stress is late. [31]

31 DAFWA. (2015) Diagnosing spring drought in narrow-leafed lupin. https://www.agric.wa.gov.au/mycrop/diagnosing-spring-drought-narrow-leafed-lupins

Photo 15: *Wilting in lupin plants due to drought conditions.*

Source: DAFWA

14.3.2 Heat stress

The direct effects of heat stress are estimated to cost grain growers about $1.1 billion nation-wide. Due to the effects of climate change, both heat stress and frost are likely to increase in the future, and will require growers to take steps to manage the risks. [32]

Lupin is sensitive to changes in ambient temperature, particularly during pod filling. Reproductive tissues are particularly sensitive to high temperature. Likely consequences of high temperatures (above 30°C) around flowering include male sterility, reduced pollen tube elongation and lowered pod and seed set. Ambient temperatures of more than 27°C can promote floret sterility and hence reduce grain yield. Episodes of 6 hours at 34, 36 or 38°C can reduce grain size by 12%. Average seed size decreases by 2% for each hour that the pods spend at temperatures greater than 35°C. [33]

IN FOCUS

Transient high temperatures during seed growth in narrow-leafed lupin: High temperatures reduce seed weight

Highly variable yields are a weakness of narrow-leafed lupins. Yield variability could be caused by many factors, including hot days during seed filling. This paper investigates the effects of 2 hot days at various stages of seed filling in narrow-leafed lupin, Merrit. Exposing adequately

32 R Barr (2016) Diversity the key to balancing frost heat risks. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks

33 Redden, R., Palta-Paz, J., Atkins, C., Gready, J. E., Dwyer, S. A., & Evans, J. R. (2013). Legume productivity and photosynthetic responses anticipated with climate change: insights from lupins. *Applying photosynthesis research to improvement of food crops*, 61.

watered plants to a total of 6 h at 34, 36, or 38˚C, compared with 20˚C, over 2 consecutive days reduced weight per seed by 4, 8, or 12% at maturity, respectively. The 38˚C treatment, applied when seeds averaged 4% of their final weight, also caused significant seed abortion. High temperatures reduced weight per seed at all stages of seed growth, except when seeds were <5–12 mg dry weight (3 and 6% of final seed dry weight, Experiments 1 and 2, respectively). The reductions in weight per seed were not associated with reduced assimilate supply because: (*a*) neither photosynthesis nor leaf longevity were reduced by heat treatment; (*b*) competing inflorescences and branches were not allowed to develop; (*c*) the plants produced very large seeds for this cultivar (174–190 mg); and (*d*) leaves remained green well after the pods had matured. Seed N concentration decreased and fat concentration increased by small, although statistically significant, amounts in response to heat treatment at the last stage of seed development tested (57% of final weight per seed when treated) but not at earlier stages. This study indicates that hot days with pod temperatures as low as 34–36˚C during seed development can cause reductions in weight per seed, and hence yields, in narrow-leafed lupin crops. [34]

14.3.3 Managing heat and drought stress

Because drought can be unpredictable and can last for extended periods of unknown length, it is difficult to prepare for it. See the links below for some tips on managing drought.

MORE INFORMATION

Sowing drought-tolerant lupins lifts crop yield

The best way to minimise the risk of damage from drought is to plant drought tolerant varieties. Over the past few decades, lupin breeding has incorporated more drought tolerant characteristics into varieties. These characteristics are now more widely available in cultivars.

Belara and Quilinock (now older varieties) were found to offer higher yields during terminal drought than other varieties. This drought tolerance was due to fast rates of seed filling, high seed number per pod and increased seed size. [35]

Some farming practices to minimise the impact of drought, by increasing the amount and retention of soil moisture include:

- Use of zero till to conserve moisture
- Using a disc machine to conserve more moisture than even a zero till machine
- Maintenance of the previous year's stubble to help conserve moisture
- Vigilant summer weed control
- Ensure starter nutrition is adequate to allow root system to be deep and extensive so it can access all available water.

In drought, it is important to not ignore the signs and to have a plan, act early, review and then plan again, and revise the plan with each action as you play out your strategy.

Step One: Check the most limiting farm resources:

- funds available;
- surface/subsoil moisture for crop leaf and root growth;
- need to service machinery – breakdowns cost time, money and frustration.

34 Reader, M. A., Dracup, M., & Atkins, C. A. (1997). Transient high temperatures during seed growth in narrow-leafed lupin (Lupinus angustifolius L.) I. High temperatures reduce seed weight. *Crop and Pasture Science*, *48*(8), 1169–1178.

35 J Palta (2002) Sowing drought-tolerant lupins lifts crop yield. Farming Ahead. http://www.farmingahead.com.au/wp-content/uploads/2016/10/FA130-38.pdf.pdf

Step Two: Set action strategies, considering:

- breakeven position of each strategy chosen;
- windows of opportunity to adopt management practices that will be profitable during drought;
- available resources and the implications for ground cover, chemical residues, etc., of carrying out each strategy;
- when situations are changing, conditional and timely fall-back options.

Step Three: Monitor and review performance, position and outlook by:

- using your established network to stay informed about key factors that affect your drought strategies;
- being proactive about the decisions made;
- being prepared for change;
- remembering that the impact falls very heavily not only on the decision makers but on the whole farm family. [36]

MORE INFORMATION

Make sure to consider the impacts of herbicide residues following drought.

Winter cropping following drought

Soil management following drought

DPI NSW Drought Hub

Drought planning

Managing drought

Soil management following drought

The principal aim after rain should be to establish either pasture or crop as a groundcover on your bare paddocks as quickly as possible. This is especially important on the red soils, but is also important for the clays. After drought, many soils will be in a different condition to what is considered to be their 'normal' condition. Some will be bare and powdery on the surface, some will be further eroded by wind or water, and some will have higher levels of nitrogen (N) and phosphorus (P) than expected. Loss of effective ground cover (due to grazing or cultivation) leaves the soil highly prone to erosion by wind and water. Research by the former Department of Land and Water Conservation's Soil Services showed that erosion due to drought-breaking rain can make up 90% of the total soil loss in a 20–30 year cycle. Following a drought, available N and P levels in the soil are generally higher than in a normal season. However, most of the N and P is in the topsoil, so if erosion strips the topsoil much of this benefit is lost. [37]

14.3.4 Storm and hail damage

Storm and hail damage can have major and unexpected impacts on crops. Events are often difficult to predict and growers can be left with few management options.

During the vegetative stage hail can shred leaves and slow crop development. Stems may be severely bruised or cut off completely (Photo 16). Later, it can remove flowers and pods or flatten crops making them hard to harvest and pods can shatter in mature pods reducing yields severely. Hail usually damages a swath through the crop. [38]

36 Meaker G, McCormick L, Blackwood I. (2007). Primefacts: Drought planning. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/96236/drought-planning.pdf

37 Jenkins A. (2007). Primefacts: Soil management following drought. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0012/104007/soil-management-following-drought.pdf

38 GRDC. Lentil ute guide. http://lentils.grdc.com.au/lentils/hail

Photo 16: *Hail and wind damage in a lupin crop in NSW.*

Photo: P Heuston

It is important to inspect damage to plants as soon as possible after a hail event as the level of damage can be obscured by subsequent growth. Although damage can be extreme, plants usually recover if hail damage occurs early in the season. Growers with hail damage insurance should contact their insurer and arrange for damage assessment.

Managing for storm and/or hail

There are few guidelines or criteria available to assist growers in making management decisions in regard to their hail damaged crop. The timing and degree of damage will influence the potential management strategies.

One management option before sowing is stubble retention, where experience has shown that 30% stubble cover gives about 70% protection from erosion during heavy storms.

Hail damage during the planting period

During the crop planting period through to the last date for replant, decisions revolve around whether to replant or not. Hail damage in these early stages causes a reduction in plant stand and plant vigour. Immediately following a hail strike a grower needs to determine whether a commercially viable stand remains, an assessment of uniformly distributed healthy plants remaining will determine if the stand is still within the commercially acceptable range. A grower would normally replant if the plant stand is lower than acceptable, but after hail the sowing window needs to be considered and the potential yield reduction from the late replant.

Hail damage when replanting is past being an option?

Following hail, crop growth is delayed and once growth restarts, it needs to mature within the remaining season if the grower is to avoid all the problems associated with late crops. Applying fertiliser following a hail event has been trialed with mixed results. [39]

39 K West (1996) Recovery from hail damage – good luck or good management? http://insidecotton.com/xmlui/bitstream/handle/1/561/10_1996_part3.pdf?sequence=1&isAllowed=y

MORE INFORMATION

Farming the business manual

Insurance

The onset of the summer storm season can deliver welcome rainfall to growers in parts of the Northern region. However, storm season can also bring severe damage, and it serves as a reminder of the climatic uncertainties in agriculture and the value of having a risk management strategy in place. [40]

14.3.5 Mice

Key points:

- Mice can cause significant damage to lupin crops.
- The risk of mouse plagues has been increased by reduced tillage, stubble retention, shallow sowing, new crop varieties and fewer livestock in farming systems.
- Grain loss at harvest is the main determinant of subsequent mouse infestation and damage in autumn, and appears to be grossly underestimated by many producers.
- Other seed sources from pasture and weeds are also significant.
- Zinc phosphide baits provide cost-effective control in most circumstances.

Mouse numbers can build and decline rapidly depending on localised conditions. Constant vigilance and timely monitoring and control are required to minimise crop loss.

Mice cannot digest cellulose, so they usually feed on the nutrient-rich plant parts: growing points, flowers and seeds. Crop damage and yield loss can be caused throughout the growing period.

Lupins are especially vulnerable to high mouse infestations, with young seedlings at the highest risk of damage (Photo 17).

Photo 17: *Young lupin plants can be completely severed.*

Source: DAFWA

Plagues usually follow good cropping years, particularly with heavy early- or late-season rains that damage maturing crops, reduce harvest efficiency, and promote unseasonable weed seed set (i.e. abundant and prolonged availability of high quality food).

40 E McNamara (2015) Reaping profits with calculated risk management. GRDC. https://grdc.com.au/news-and-media/news-and-media-releases/north/2015/12/reaping-profits-with-calculated-risk-management

Mice are always present in crops in low numbers, but can increase rapidly under favourable conditions. The increased frequency of plagues has been caused by changes in cropping systems that use less cultivation, stubble retention, more diverse crops, and fewer livestock. These changes provide mice with better cover, more high-quality food, undisturbed burrows and easy access to sown grain. The end result is both more mice for any given seasonal conditions, and more damage to crops for a given number of mice.

It is important that landholders become familiar with indicators of 'normal' mouse activity for their properties.

When mouse numbers have been high in autumn, monitoring should continue through winter and spring. Indicators that mouse numbers have increased include:

- numerous burrows (Photo 18);
- mouse droppings on soil and plants, and the typical mousey smell;
- large numbers of mice seen at night, in paddocks or on roads;
- more birds of prey (such as kestrels or kites) than normal;
- signs of seeds being dug up, plants being gnawed or pod and head damage; and
- frequent day-time sightings.

Simple in-paddock monitoring techniques can be used if conditions indicate the risk of increases in mouse populations or if early signs are evident. Hole counts and census cards provide an indication of mouse activity, while trapping provides the opportunity to assess populations and breeding status.

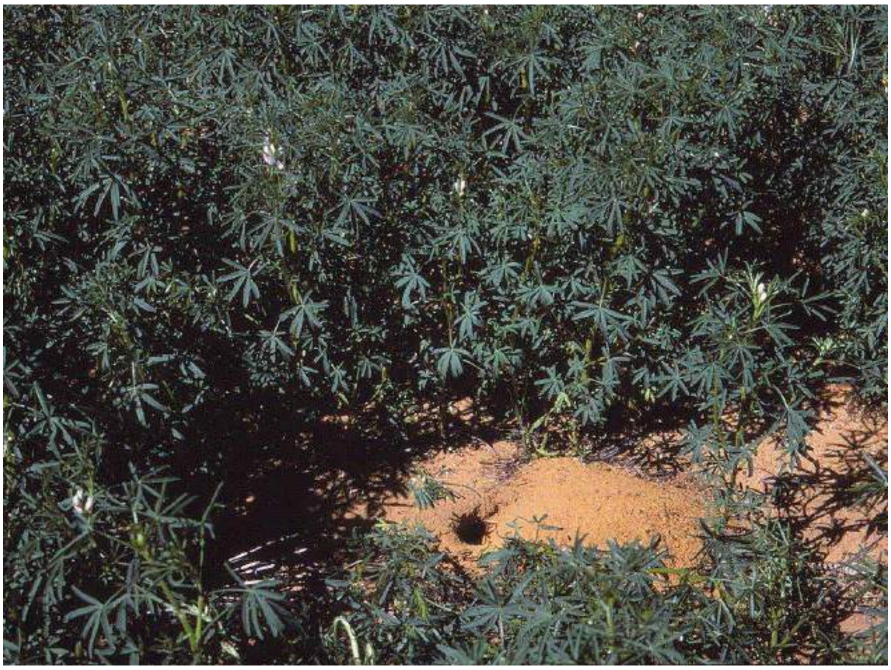


Photo 18: *Bare patches and chewed plants radiating out from mouse burrows in a lupin crop.*

Source: DAFWA

MORE INFORMATION

Mouse monitoring a must to reduce crop damage risk

MouseAlert – App

Grain growers are encouraged to keep a close eye on mouse activity over the coming crop growing and harvesting season and regularly record their observations via MouseAlert.

MouseAlert aims at improving early warning of possible plagues to enable a rapid response to increases in mouse activity.

MORE INFORMATION

MouseAlert

MouseAlert can be used to map where mice are and where they aren't, so participants can play a vital role in developing a better picture of mice distribution and numbers.

Managing mouse plagues

Keeping your farm clean – minimising the supply of quality feed through good harvesting techniques and cleaning up grain spills around stores and in the paddock – helps reduce the potential for the mouse breeding period to extend into late autumn/winter. An integrated approach to control needs to be taken to help ensure feed supplies are minimised, especially in seasons conducive to mouse population build-up.

Operations

- Control weeds and volunteers along fence lines, crop margins and channel banks in autumn and before seed-set to minimise sources of food and shelter.
- Rotations – chickpeas after barley are considered a higher risk than beans if mouse numbers are high.
- Sow as evenly and as early as possible for each crop, to achieve rapid establishment of strong plants. Do not dry sow.
- Slightly increase seeding rates and sow as deeply as possible for each crop if mouse numbers are elevated at seeding.
- Cross harrow or roll after sowing to ensure good seed coverage and the removal of sowing lines.
- When mouse populations are high at seeding, these cultural practices are often insufficient to control damage and baiting at sowing may be necessary.
- Harvest crops before they are overripe and pod shatter or grain loss occurs

Hygiene

- Minimising spilled grain in paddocks is key to limiting mouse populations and damage in next year's crop.
- Set harvesters to minimise grain loss and monitor how much grain is left in the paddock.
- Heavy grazing can help clean up high harvest grain losses, but sufficient ground cover should be left to minimise erosion potential.
- Clean up any concentrated spills of grain around field bins, augers, silo bags and other grains storage.
- Remove or reduce cover, including plant material, rubbish and general clutter around buildings, silos and fodder storage as these all provide protection for mice.

In crop baiting

Baiting is not a total solution for crop protection, but assists in minimising potential damage. Baiting only kills those mice that eat the bait. In trials, 90% of the mouse population in the baited area were killed. Two rodenticides are currently registered for field use: bromadiolone and zinc phosphide. The GRDC is continuing research on mouse bait technology.

Zinc phosphide is registered for incrop use only. Growers should consult the label for use instructions. Strict baiting criteria have been established to minimise risks associated with the release of toxic phosphine gas. The gas is not readily released into the atmosphere and the concentrations are insufficient to be harmful to grazing animals or humans. However, bee hives should be moved away from areas that will be baited. Aerial or ground application can be used to spread zinc phosphide bait. A rate of 1 kg/ha provides 20,000 lethal doses per hectare. It can be spread in stubble, pasture and crop, or a vegetative fallow, but not on bare ground.

Ideally, mouse bait should be used in dry conditions to achieve maximum ingestion of the active ingredients. Baiting at the time of sowing, or immediately after, is most

MORE INFORMATION

[Mouse management – on-going control](#)

[Mouse control – minimising crop damage](#)

[Mice – they're back again](#)

effective for protecting recently sown crops. Baiting is also effective for controlling mouse damage during vegetative growth, flowering and seed set. After baiting, mouse activity should continue to be monitored and rebaiting should not occur for 14 days. Baiting must not occur within two weeks of harvest, due to the withholding period. Bait must not be laid within 50m of the crop perimeter or native vegetation. [41]

14.3.6 Feral pig damage

Records indicate the presence of domestic pigs immediately following the arrival of the First Fleet. Pigs were kept by settlements unrestrained and in semi-feral conditions. Stock could readily escape and wander, and by the 1880s there were many feral pig populations across the Northern region.

Feral pigs reduce yields in grain crops by consuming or trampling plants. [42] They can have a significant impact on lupin crops (Photo 19). The two main times they affect lupins is at sowing and when the crop is mature. Pigs favour lupins and will literally put their snout in the ground and plough down a sown row and eat every seed they come across. Resulting in not only a poor plant stand but a very uneven soil surface. Pigs like tall crops to hide in and as such find mature lupin crops very appealing. they will eat the pods off the plants but cause more damage by knocking over plants and even creating nests or places to sleep within a crop.

Photo 19: *Damage to crops in Condamine NSW caused by feral pigs (left) and close up damage to a lupin crop at Nyngan in NSW (right).*

Photo: S Bridle and T Whiteley.

Management of feral pigs

Management of feral pigs and the impact they cause will normally require a number of methods in combination. The first step is identifying feral pig presence and/or damage.

Recognition and signs

There are a number of signs and pieces of evidence to indicate feral pig activity and abundance in an area. Regular sightings of pigs and abundant fresh sign normally means high numbers of feral pigs; some sightings of pigs and obvious fresh sign indicates medium numbers of feral pigs.

The signs of feral pig populations include:

- **Direct observation**
- **Crop damage:** Feral pigs damage crops by eating them, by trampling and bedding in them, and by uprooting seed and seedlings. Their rooting is

41 GRDC (2011) Mouse management factsheet – on-going control of mice. https://grdc.com.au/__data/assets/pdf_file/0020/202565/grdc_mice_fs.pdf

42 NSW DPI. Feral pig biology. http://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/pest-animals-in-nsw/feral-pigs/feral-pig-biology

distinctive, but their trampling, pads/paths and bedding may also resemble damage caused by kangaroos.

- **Rooting:** Feral pigs use their snouts and teeth to dig for underground food, including small animals and tubers, particularly where soil is soft or after rain.
- **Lamb predation**
- **Fence damage:** Pigs will push through fences, usually next to a post or picket and these holes are then used by other animals. Mud or coarse bristly hair on the wire or post indicates feral pigs.
- **Pads:** Pigs often create pads when travelling in single file to frequently used food and water sources.
- **Tracks:** Feral pigs leave hoof-prints in any soft surface. Their tracks have a distinctive shape but can be easily confused with sheep tracks if the outline is blurred.
- **Faeces:** The size, shape and consistency of the scat varies with age and diet, but it is typically 3 to 6 cm wide, 7 to 22 cm long and fairly well formed.
- **Wallows**
- **Mud-rubs:** After wallowing, pigs often rub their heads, shoulders and sides on nearby vertical objects such as tree trunks and fence posts.
- **Tusk-marks**
- **Nests:** Just before farrowing, sows make nests from the available vegetation, which they uproot and carry by mouth. If long, grassy vegetation is plentiful, the nest can be very large - up to 3 m by 1.5 m and 1 m high, with a domed roof. Nests are usually less than 2 km from permanent water. [43]

MORE INFORMATION

Feral pig biology

Fencing

Fencing is sometimes used to protect valuable enterprises in small areas. Effective pig-proof fences have been designed but need to be thoroughly maintained to maintain effectiveness.

Baiting

Ground baiting with 1080 poison can be an effective initial control of pig numbers if undertaken in a methodical manner. It is particularly effective if green feed and other food sources are scarce. Only Authorised Control Officers (ACOs) in NSW can prepare bait and supply it to land managers.1080 bait can only be used in bait stations. 1080 poison is regulated under a current 1080 Pesticide Control Order (PCO) that details the particulars of its use. The use of 1080 currently requires a minimum chemical use accreditation at AQF3 level or training specified in the 1080 PCO.

Aerial baiting programs may be an effective means for dealing with a feral pig problem where ground control is impractical or where impacts are significant or potentially significant. There are a number of restrictions and legal requirements associated with aerial baiting programs. A land manager should discuss the intended program with the ACO of Local Land Services several months in advance. Growers who undertakes aerial baiting must only use Pigout® Feral Pig Bait and it can only be applied by helicopter.

Shooting

Shooting feral pigs from helicopters is an effective method for an initial knockdown of numbers. This type of shooting is species-specific and can be used in areas that are inaccessible from the ground. Helicopter shooting can be expensive if not properly planned, so it is important to have coordination and cooperation from a number of groups or organisations.

Shooting feral pigs from the ground is a method normally used opportunistically to follow up and maintain numbers after an initial knockdown program has occurred. Often ground shooting is conducted using dogs to locate feral pigs. This can be

43 NSW DPI. Feral pig biology. http://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/pest-animals-in-nsw/feral-pigs/feral-pig-biology

effective as long as both the dogs and the pigs are treated in a humane fashion. Ground shooting should not be conducted prior to, or during, any other program of control, as it disrupts normal feral pig activity and may cause feral pigs to temporarily disperse to other areas.

Trapping of feral pigs is an effective technique to use as a follow-up after an initial knockdown of a population and as a maintenance technique to prevent numbers from quickly building back up. Trapping is flexible, as most traps can be easily moved to where pig activity is current. The exact numbers of pigs controlled is known and there is no danger to livestock or other domestic animals; where available, carcasses can be sold to a chiller. As traps are checked daily they pose little risk to wildlife.

Enterprise change

A decision may be made that a viable option is to change the type of enterprise in areas susceptible to the impact from pigs, for example, to change from lambs and lambing paddocks to wethers, from grazing to farming or from farming to grazing. This is normally a last resort but does occur in some instances. [44]

MORE INFORMATION

Feral pig control

44 NSW DPI. Feral pig control. http://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/pest-animals-in-nsw/feral-pigs/feral-pig-control

Marketing

The final step in generating farm income is converting the tonnes produced into dollars at the farm gate. This section provides best in class marketing guidelines for managing price variability to protect income and cash-flow.

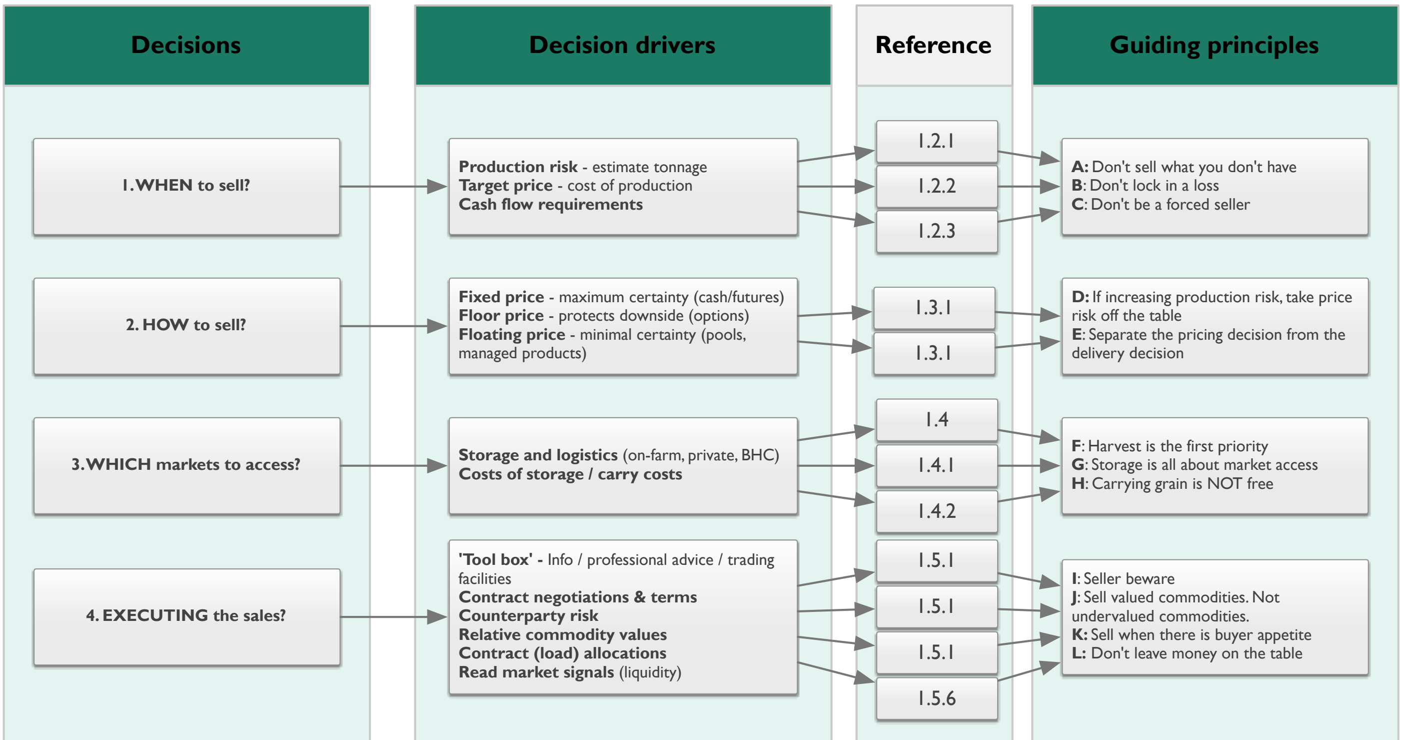


Figure 1: *Grain selling flow chart*

Figure 1 shows a grain selling flow chart that summarises:

- The decisions to be made
- The drivers behind the decisions
- The guiding principles for each decision point

References are made to the section of the GrowNote you will find the detail.

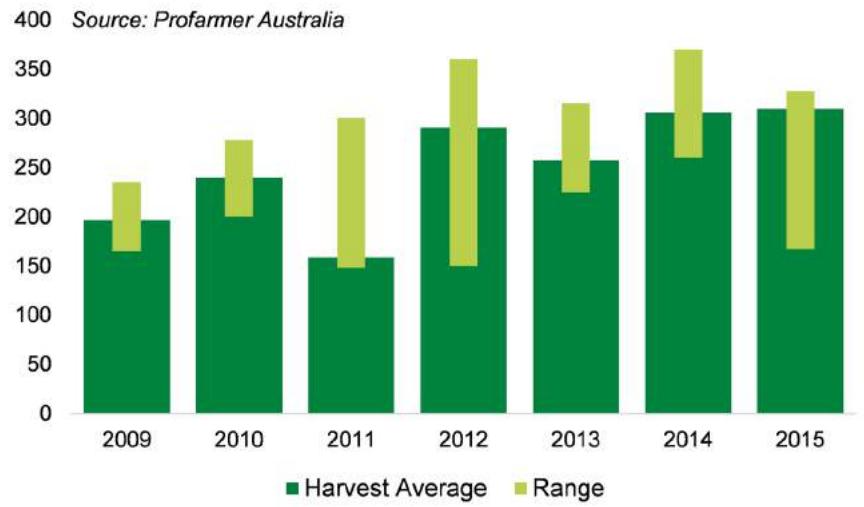


Figure 2: *Intraseason variance of Port Lincoln Lupin Values.*

Note to figure: Port Lincoln Lupin values have varied A$70-$210/t over the past 7 years (representing variability of 30–90%). For a property producing 200 tonnes of lupins this means $14,000-$42,000 difference in income depending on timing of sales.

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 work 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:

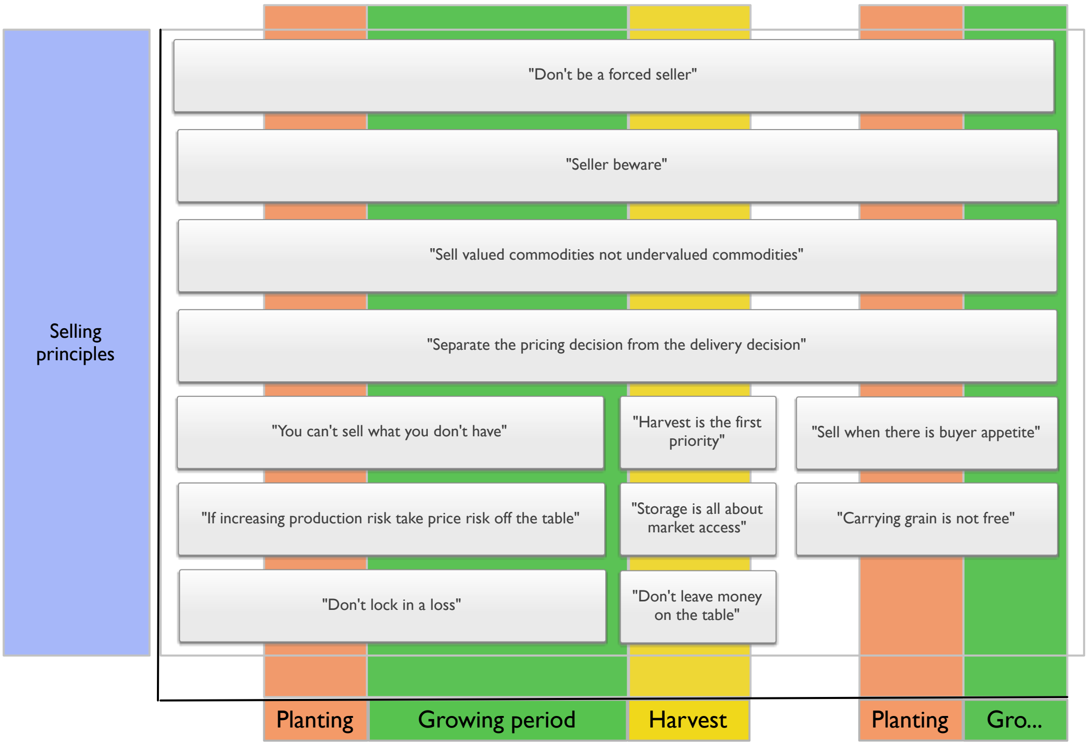
- production risk
- a target price based on cost of production and a desired profit margin
- business cash flow requirements

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 lists key selling principles when considering sales during the growing season.



Note to *figure*:
The illustration demonstrates the key selling principles throughout the production cycle of a crop.

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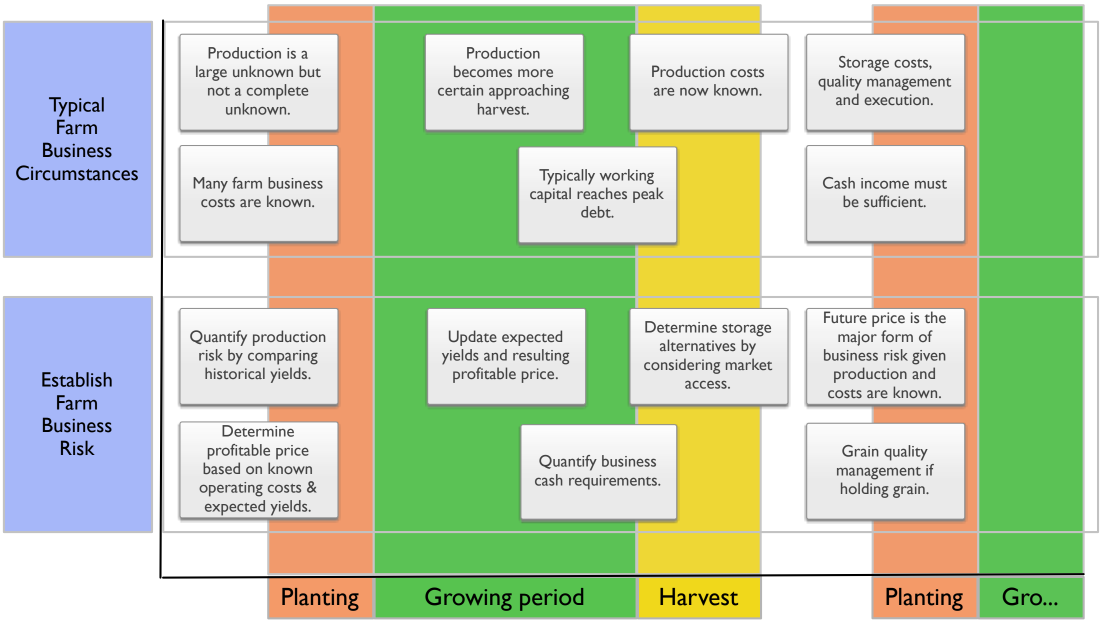
Figure 3: *Grower commodity selling principles timeline*

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.



Note to *figure*:
When does a grower sell their grain? This decision making is dependent on:
a) Does production risk allow sales? And what portion of production?
b) Is the price profitable?
c) Are business cash requirements being met?

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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.

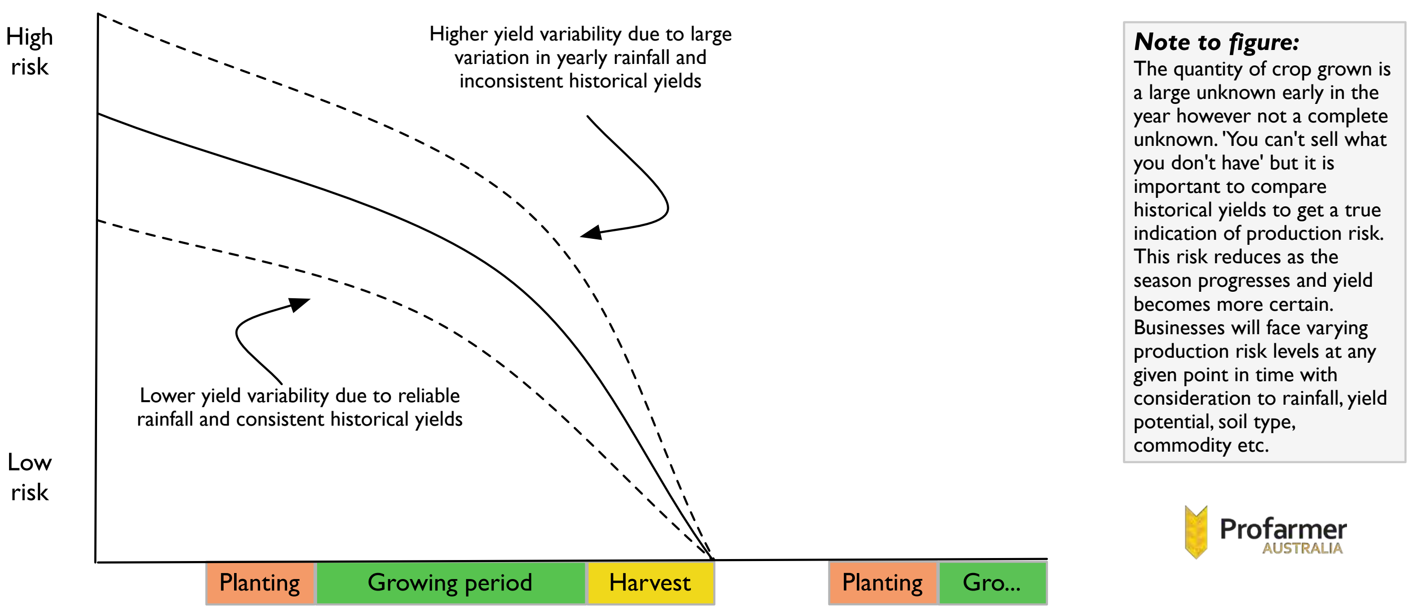


Figure 5: *Typical risk profile of farm operation*

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	
Estimate Yield	2.85 t/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.
Estimated Production	3,420 t	
Fixed costs		
Insurance and General Expenses	$100,000	
Finance	$80,000	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 Krause "Farming your Business") but the most important thing is that in the end all costs are accounted for.
Depreciation/Capital Replacement	$70,000	
Drawings	$60,000	
Other	$30,000	
Variable costs		
Seed and sowing	$48,000	
Fertiliser and application	$156,000	
Herbicide and application	$78,000	Step 3: Calculate all the variable costs attributed to producing that crop. This can also be expressed as $ per ha x planted area.
Insect/fungicide and application	$36,000	
Harvest costs	$48,000	
Crop insurance	$18,000	
Total fixed and variable costs	$724,000	
Per Tonne Equivalent (Total costs + Estimated production)	$212 /t	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	
Receival fee	$11 /t	
Freight to Port	$22 /t	
Total per tonne costs	$48 /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	Step 7: Add a desired profit margin to arrive at the port equivalent target profitable price.
Target profit (ie 20%)	$52.00	
Target price (port equiv)	**$311.20**	

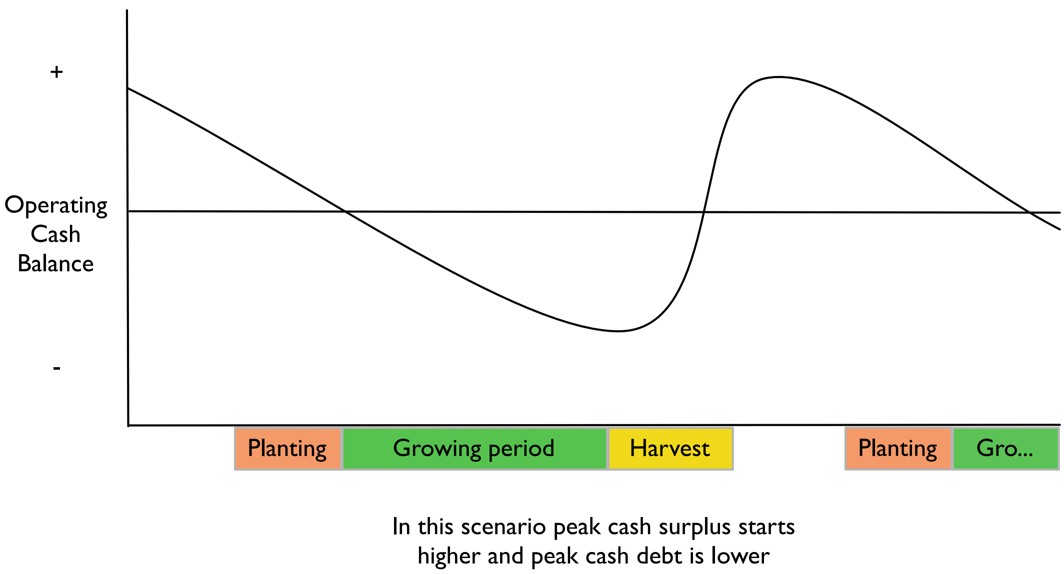
Figure 6: *GRDC's "Farming the Business Manual" also provides a cost of production template and tips on grain selling vs grain marketing.*

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.

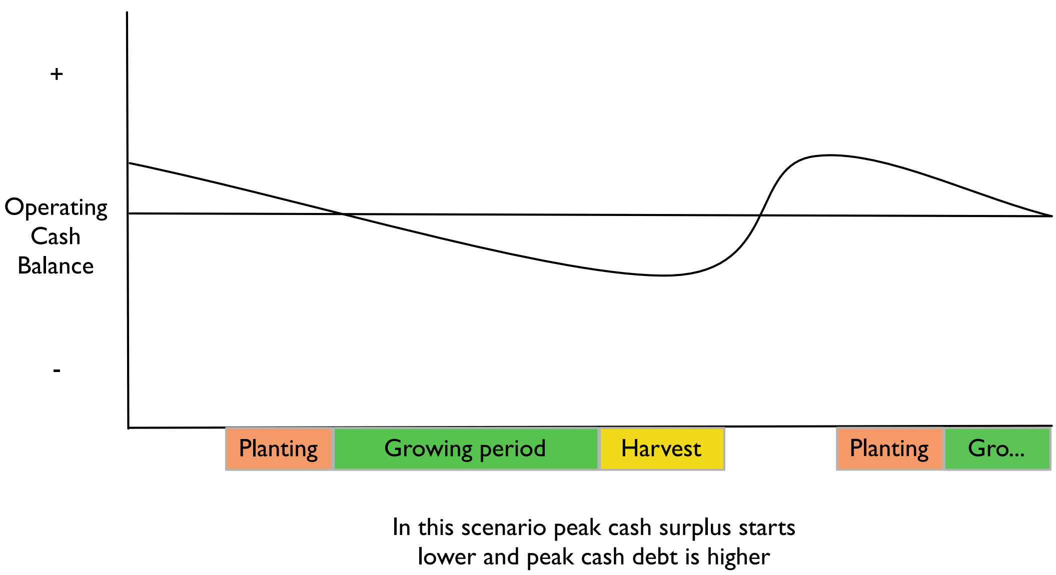
Principle: "Don't be a forced seller" – Be ahead of cash requirements to avoid selling in unfavourable markets.

A typical cash-flow to grow a crop is illustrated below. 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.



Note to figure:
The chart illustrates the operating cash flow of a typical farm assuming a heavy reliance on cash sales at harvest. Costs are incurred during the season to grow the crop, resulting in peak operating debt levels at or near harvest. Hence at harvest there is often a cash injection required for the business. An effective marketing plan will ensure a grower is 'not a forced seller' in order to generate cash flow.

Figure 7: *Typical operating cash balance*



Note to figure:
By spreading sales throughout the year a grower may not be as reliant on executing sales at harvest time in order to generate required cash flow for the business. This provides a greater ability to capture pricing opportunities in contrast to executing sales in order to fulfil cash requirements.

Figure 8: *Typical operating cash balance*

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 different crops.*

	Description	Wheat	Barley	Canola	Oats	Lupins	Field peas	Chick peas
Fixed price products	Provides the most price certainty	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash	Cash	Cash	Cash
Floor price products	Limits price downside but provides exposure to future price upside	Options on futures, floor price pools	Options on futures	Options on futures	none	none	none	none
Floating price products	Subject to both price upside and downside	Pools	Pools	Pools	Pools	Pools	Pools	Pools

The diagram below provides a summary of where different methods of price management are suited for the majority of farm businesses.

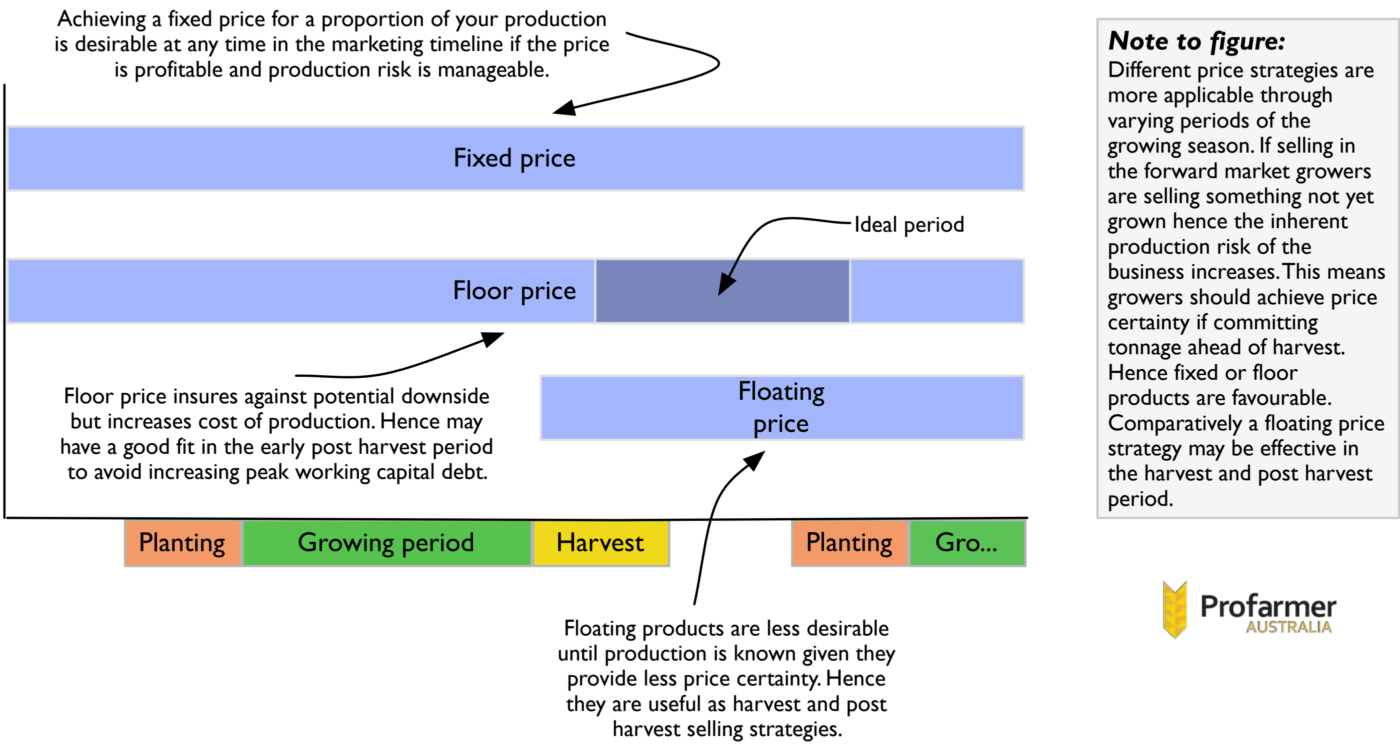


Figure 9: *Summary of where different methods of price management are suited for the majority of farm businesses.*

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.

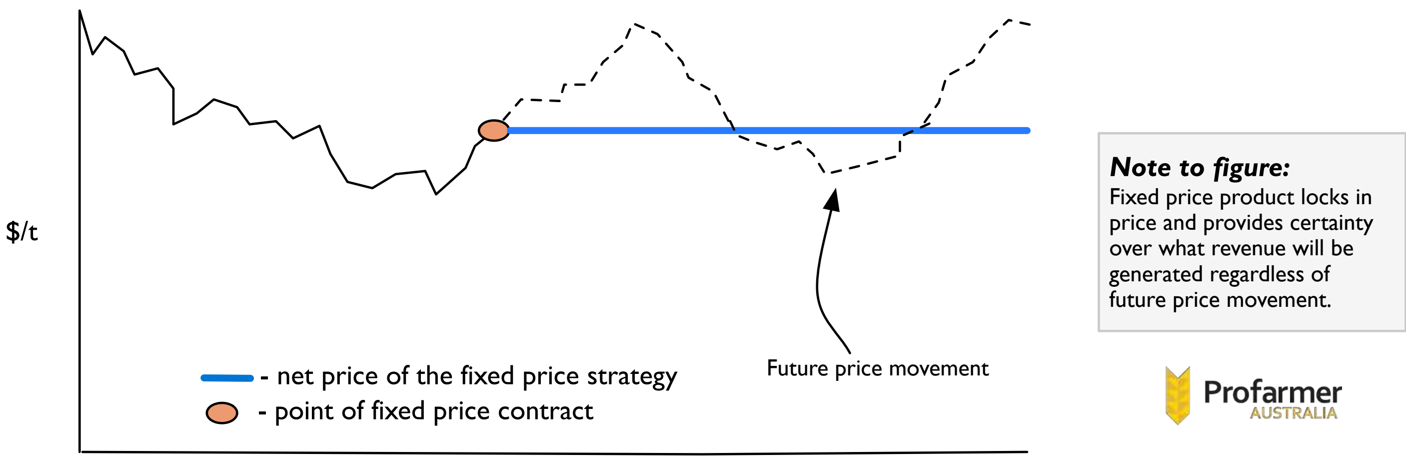


Figure 10: *Fixed price strategy*

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 (ie. 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.

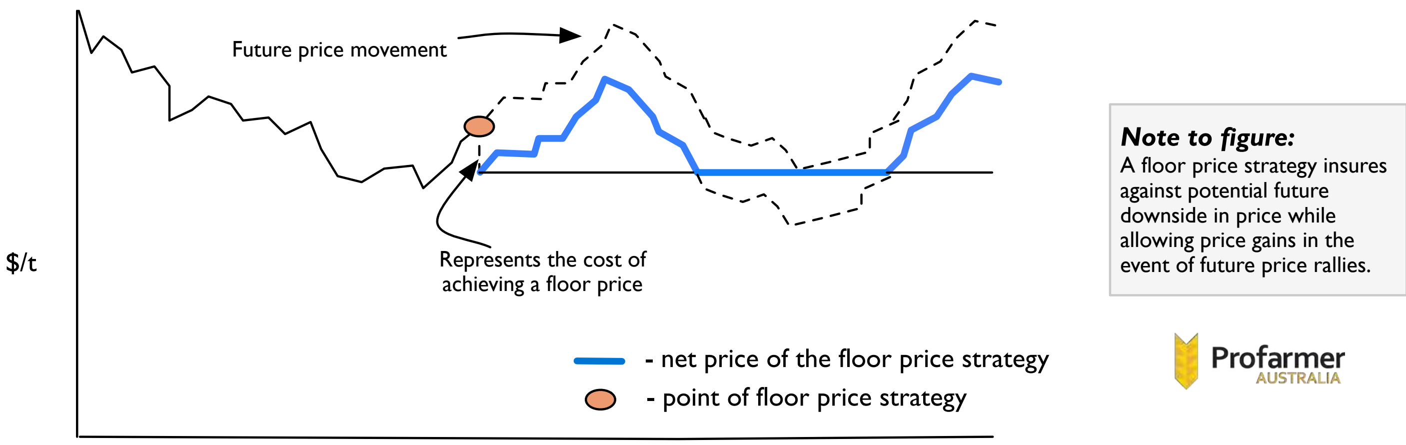
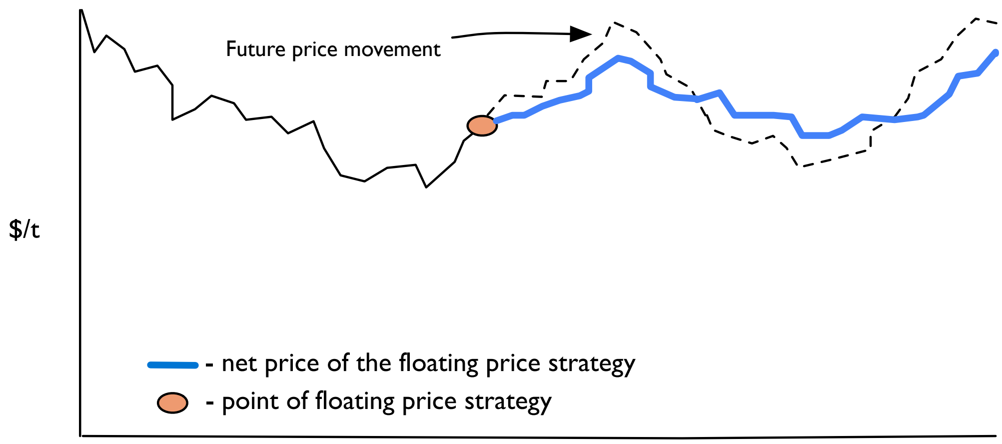


Figure 11: *Floor price strategy*

3. 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.



Note to figure:
A floating price will move to some extent with future price movements.

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Figure 12: *Floating price strategy*

4. How to sell revised

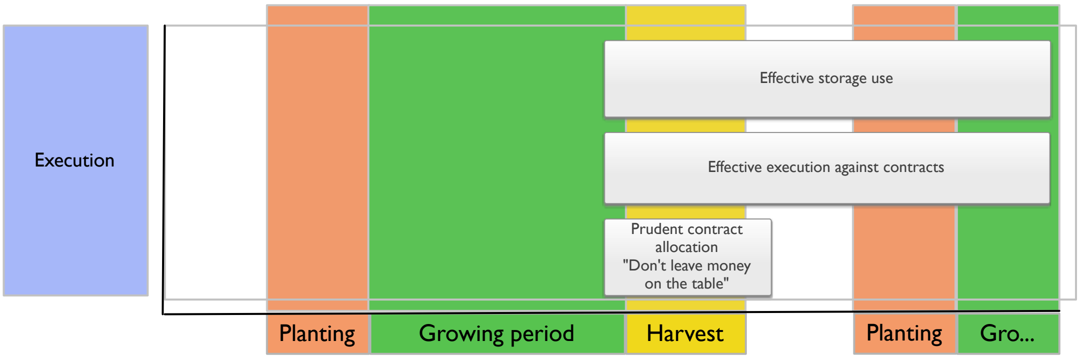
Fixed price strategies include physical cash sales or futures products and provide the most price certainty but production risk must be considered.

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.



Note to figure:
Once a grower has made the decision to sell the question becomes how they achieve this? The decision on how to sell is dependent on:
a) Time of the year determines the pricing method
b) Market Access determines where to sell.
c) Relative value determines what to sell.

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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.

MORE INFORMATION

For more information on on-farm storage alternatives and economics refer Section 13. Grain Storage.

For more information on on-farm storage alternatives and economics refer GRDC Western Region - Wheat - GrowNote, Section 14 Grain Storage

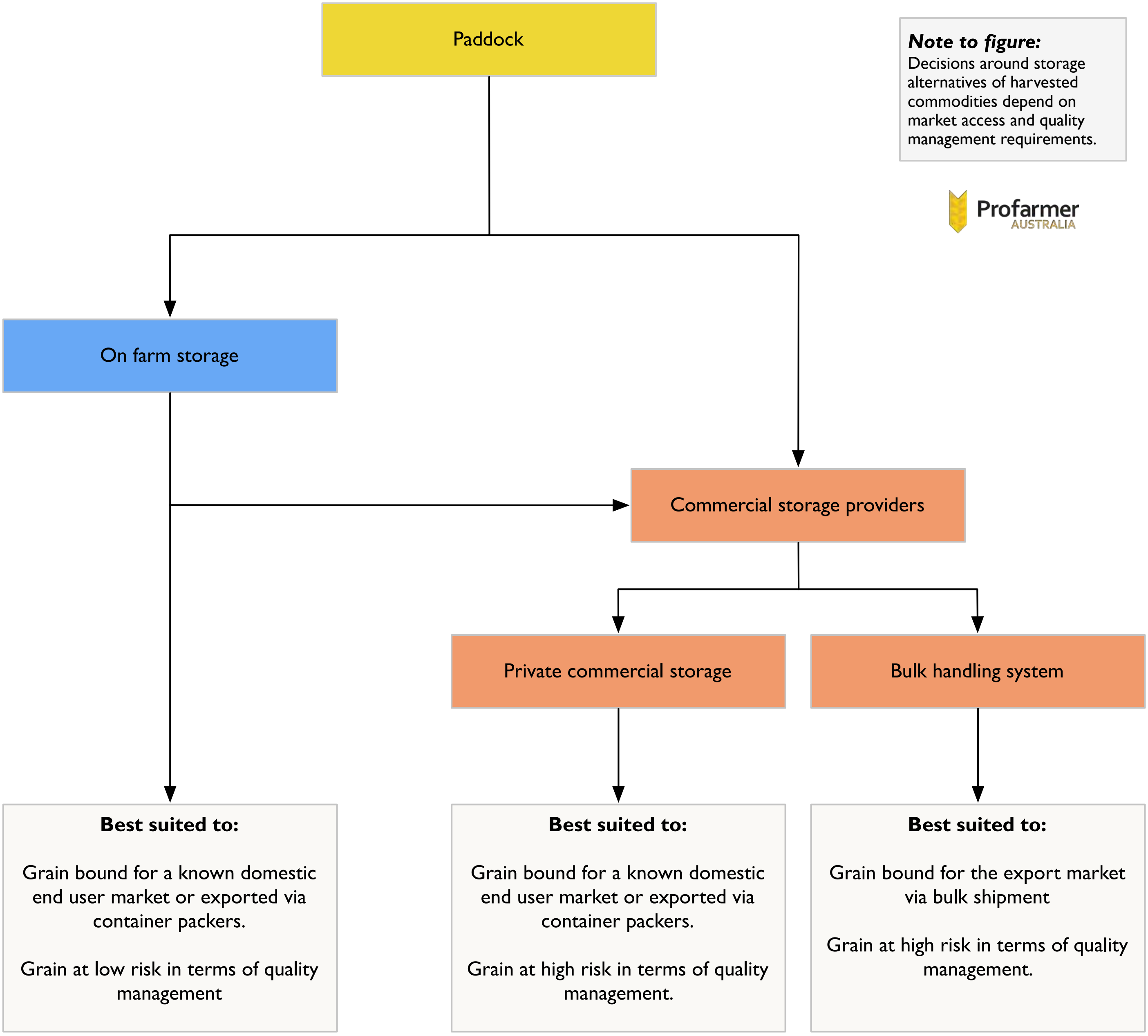


Figure 14: *Grain storage decision making*

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:

1. monthly storage fee charged by a commercial provider (typically ~$1.50–2.00/t per month)
2. the interest associated with having wealth tied up in grain rather than cash or against debt (~$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.

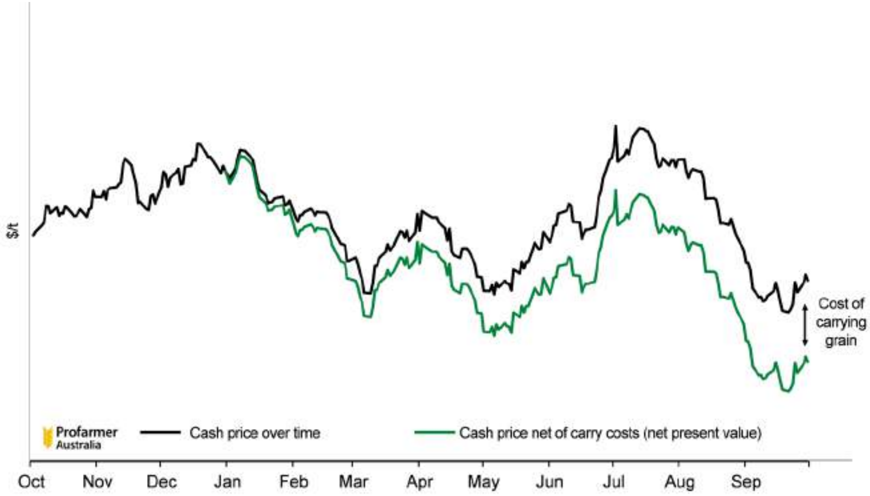


Figure 15: *Cash values vs cash adjusted for the cost of carry*

Note to figure: if selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example on the case of a March sale for March –June delivery on the buyers call at $400/t + $3/t carry per month, if delivered in June this contract would generate revenue of $409/t delivered.

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.

MORE INFORMATION

http://www.graintrade.org.au/membershiphttp://www.graintrade.org.au/membership

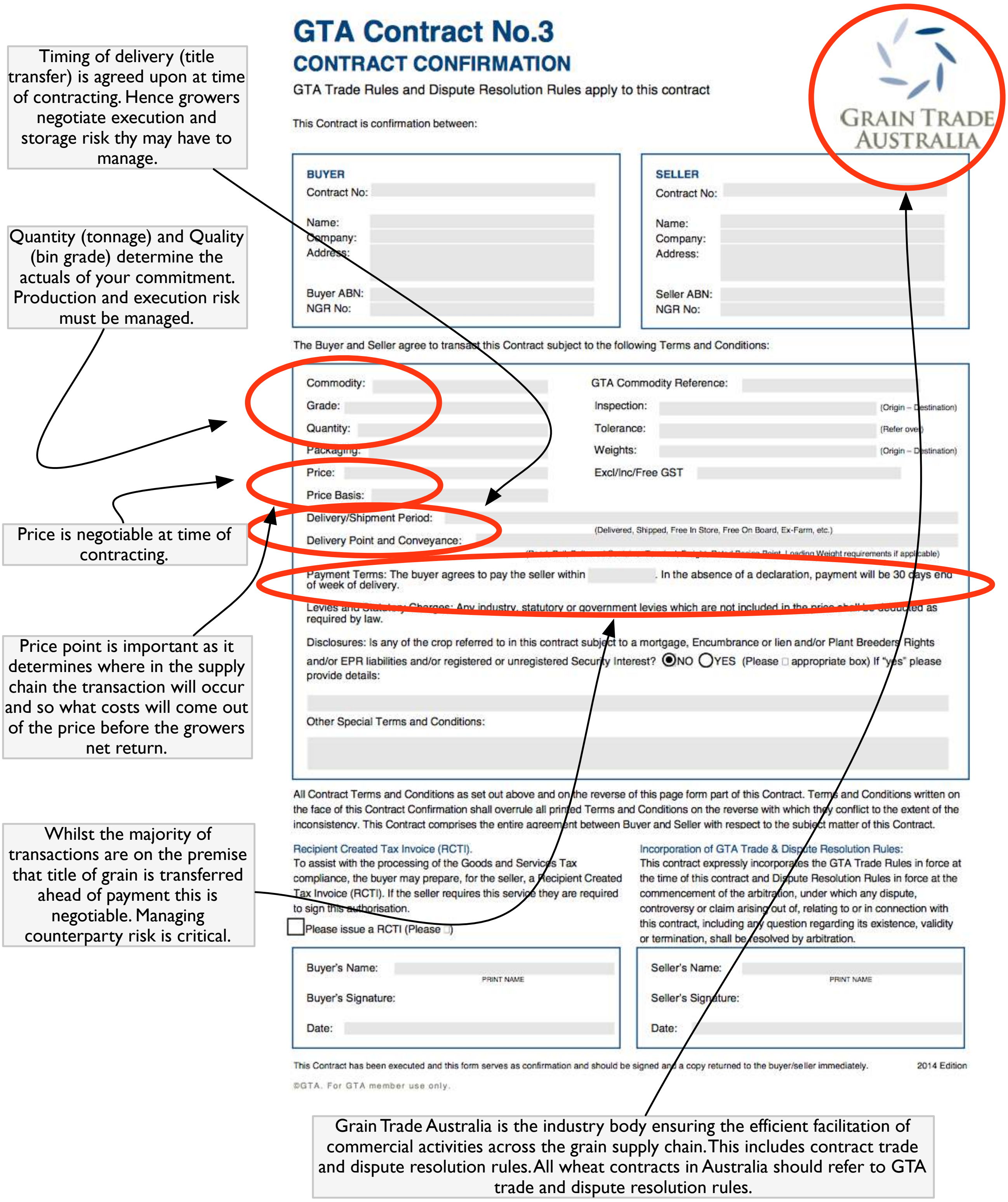
http://www.asx.com.au/prices/find-a-futures-broker.htmhttp://www.asx.com.au/prices/find-a-futures-broker.htm

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.



GTA Contract No.3

CONTRACT CONFIRMATION

GTA Trade Rules and Dispute Resolution Rules apply to this contract

This Contract is confirmation between:

BUYER	SELLER
Contract No:	Contract No:
Name:	Name:
Company:	Company:
Address:	Address:
Buyer ABN:	Seller ABN:
NGR No:	NGR No:

The Buyer and Seller agree to transact this Contract subject to the following Terms and Conditions:

Commodity:	GTA Commodity Reference:
Grade:	Inspection: (Origin – Destination)
Quantity:	Tolerance: (Refer over)
Packaging:	Weights: (Origin – Destination)
Price:	Excl/Inc/Free GST
Price Basis:	

Delivery/Shipment Period: (Delivered, Shipped, Free In Store, Free On Board, Ex-Farm, etc.)

Delivery Point and Conveyance: Loading Weight requirements if applicable)

Payment Terms: The buyer agrees to pay the seller within . In the absence of a declaration, payment will be 30 days end of week of delivery.

Levies and Statutory Charges: Any industry, statutory or government levies which are not included in the price shall be deducted as required by law.

Disclosures: Is any of the crop referred to in this contract subject to a mortgage, Encumbrance or lien and/or Plant Breeders Rights and/or EPR liabilities and/or registered or unregistered Security Interest? NO YES (Please appropriate box) If "yes" please provide details:

Other Special Terms and Conditions:

All Contract Terms and Conditions as set out above and on the reverse of this page form part of this Contract. Terms and Conditions written on the face of this Contract Confirmation shall overrule all printed Terms and Conditions on the reverse with which they conflict to the extent of the inconsistency. This Contract comprises the entire agreement between Buyer and Seller with respect to the subject matter of this Contract.

Recipient Created Tax Invoice (RCTI).
To assist with the processing of the Goods and Services Tax compliance, the buyer may prepare, for the seller, a Recipient Created Tax Invoice (RCTI). If the seller requires this service they are required to sign this authorisation.
Please issue a RCTI (Please)

Incorporation of GTA Trade & Dispute Resolution Rules:
This contract expressly incorporates the GTA Trade Rules in force at the time of this contract and Dispute Resolution Rules in force at the commencement of the arbitration, under which any dispute, controversy or claim arising out of, relating to or in connection with this contract, including any question regarding its existence, validity or termination, shall be resolved by arbitration.

Buyer's Name: PRINT NAME	Seller's Name: PRINT NAME
Buyer's Signature:	Seller's Signature:
Date:	Date:

This Contract has been executed and this form serves as confirmation and should be signed and a copy returned to the buyer/seller immediately. 2014 Edition

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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.

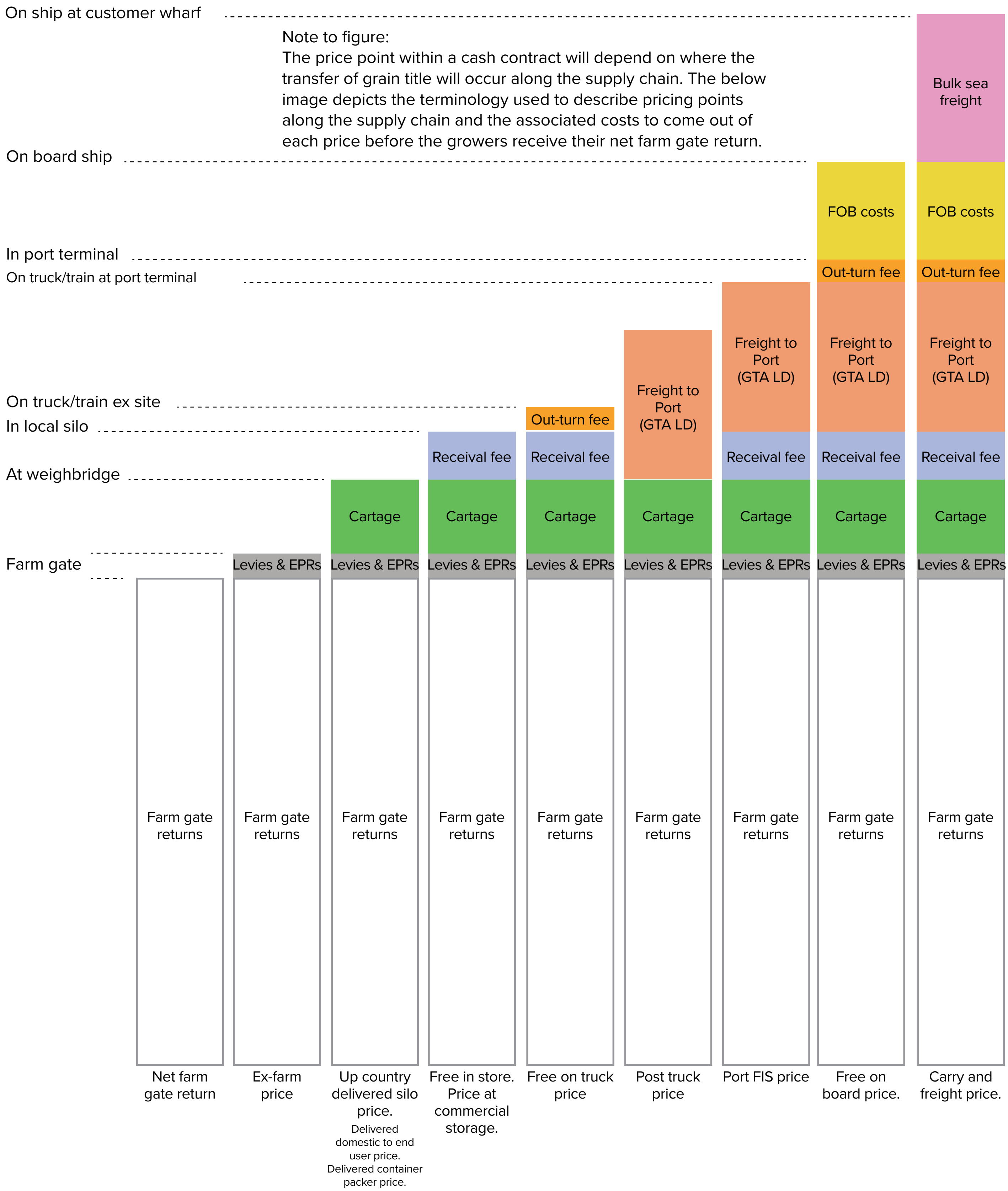


Figure 17: *Cost and pricing points throughout the supply chains*

MORE INFORMATION

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

https://www.cleargrain.com.au/get-started

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

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 matches, the parcel transacts via a secure settlement facility where title of grain does not transfer from the grower until funds are received from the buyer. The availability of this depends on location and commodity. Anonymous firm offers can also be placed to buyers by an intermediary acting on behalf of the grower. If the grain sells, the buyer and seller are disclosed to each counterparty.

Counterparty risk

Most sales involve transferring title of grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: "Seller beware" – There is not much point selling for an extra $5/t if you don't get paid.

Counterparty risk management includes:

- Dealing only with known and trusted counterparties.
- Conduct a credit check (banks will do this) before dealing with a buyer they are unsure of.
- Only sell a small amount of grain to unknown counterparties.
- Consider credit insurance or letter of credit from the buyer.
- Never deliver a second load of grain if payment has not been received for the first.
- Do not part with title of grain before payment or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting, alternatively the Clear Grain Exchange provides secure settlement where-by the grower maintains title of grain until payment is received by the buyer, and then title and payment is settled simultaneously.

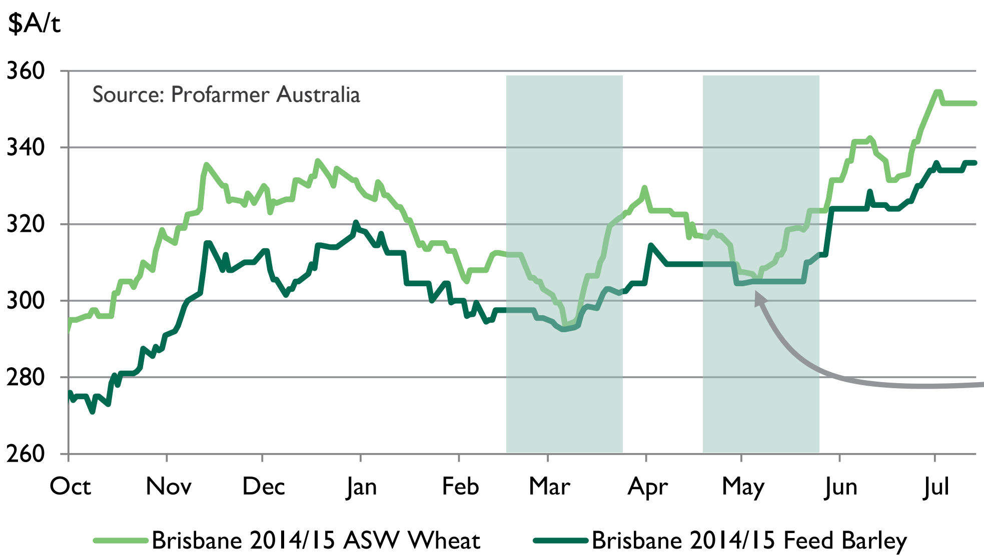
Above all, act commercially to ensure the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving $5/t more and not getting paid is a disastrous outcome.

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.

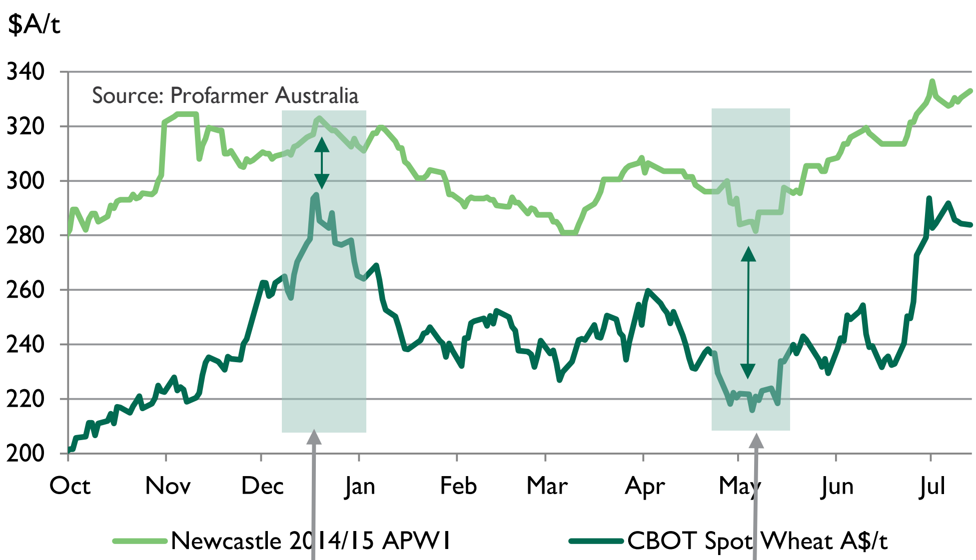


Note to figure:
Price relativities between commodities is one method of assessing which grain types 'hold the greatest value' in the current market.

Example:
Feed barley prices were performing strongly relative to ASW wheat values (normally ~15% discount) hence selling feed barley was more favourable than ASW wheat during this period.

Figure 18: *Brisbane 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.



Note to figure:
Once the decision to take price protection has been made, choosing which pricing method to use is determined by which selling methods 'hold the greatest value' in the current market.

Example:
Sales via CBOT wheat were preferred over cash.

Example:
Cash sales were preferred over CBOT wheat.

Figure 19: *Newcastle APWI vs CBOT wheat A$/t*

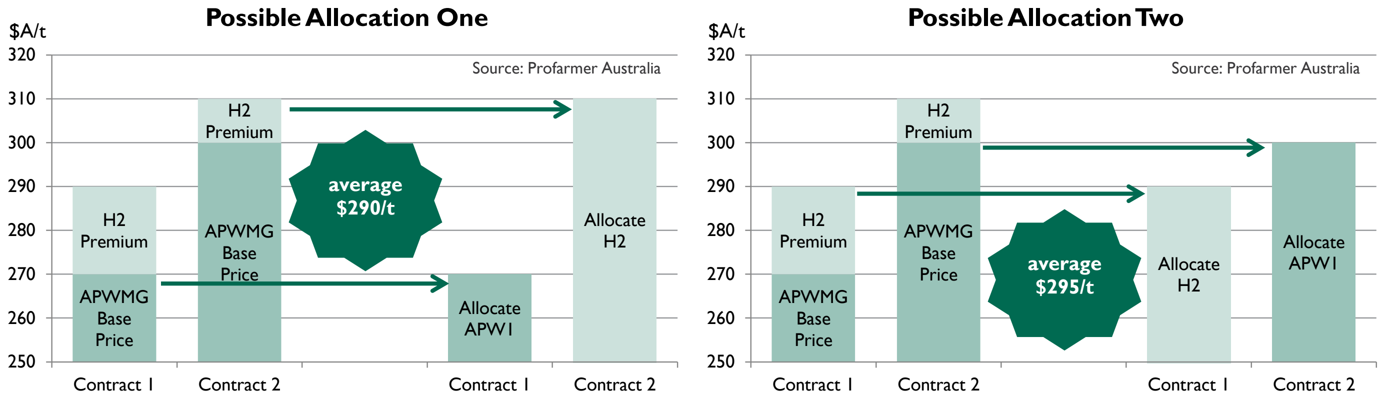
Contract allocation

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. The chart below plots actual trade prices on the Clear Grain Exchange against the best public indicative bid on the day.

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 lupins – market dynamics and execution

15.2.1 Price determinants for Northern lupins

Australia is a relatively small player in terms of world pulse production, producing 1.5–2.5 million tonnes of pulses in any given year vs global production of approximately 60 million tonnes. Lupins makeup only a small part of this global pulse complex with estimates pointing to only marginally more than a million tonnes being produced annually. Australia however makes up a considerable proportion of the global lupin production. Australian annual production has ranged from 550–650 thousand tonnes in recent seasons, accounting for 50–80% of global production and positioning it as the key global market participant.

There are two major types of lupins grown in Australia. The Sweet lupin is the predominant variety grown, with the bulk of the production occurring in WA. This variety is predominately used for stockfeed and with a relatively small domestic stockfeed market in WA the majority of the WA production is exported. Comparatively the Albus lupin is primarily used for human consumption purposes and production although considerably smaller is spread throughout NSW, Vic, SA and WA. In the northern growing regions lupins are limited to southern NSW with a 50–50 split between the two varieties with annual production of the two combined ranging from 50–80 thousand tonnes each year.

The major export markets for lupins varies depending on the variety. The export market for Albus lupins is primarily Egypt, where they're used for human consumption within the snackfood industry. With the Egyptian import requirement estimated at just 50,000 tonne each year a change in Australian production for this variety can result in a notable under or over supply. Comparatively the major export markets for the Sweet lupin consist of South Korea, the European Union and Japan, who between them import on average 200–350 thousand tonnes of Australian lupins each year to be used as stockfeed.

With lupins predominately exported for stockfeed they are valued in relation to other competing protein commodities. Australia is typically the sole exporter of lupins into the global market, hence rather than competing against other export origins competes against substitute protein products, with the biggest being the soybean complex. Lupins into export markets are typically valued at a price relative to that of soybean meal. Given this dynamic Australian farm gate prices are heavily influenced by both local production volatility as well as international trade values for substitute protein products such as soybean meal.

Some of the global influences on Australian lupin pricing are listed below:

1. The world price and availability of soybean meal is the largest influence on export values of Australian lupins. Soybean meal is the most heavily produced protein that can act as a substitute for lupins.
2. Lupin production in origins outside of Australia. While Australia is by far and away the largest producer of lupins globally, if production increases in outside regions it can impact the import requirements for Australian produce in the coming season. This is particularly true in the EU where increases in production throughout the EU can result in reduced appetite from neighbouring nations and key importers including Spain and the Netherlands.

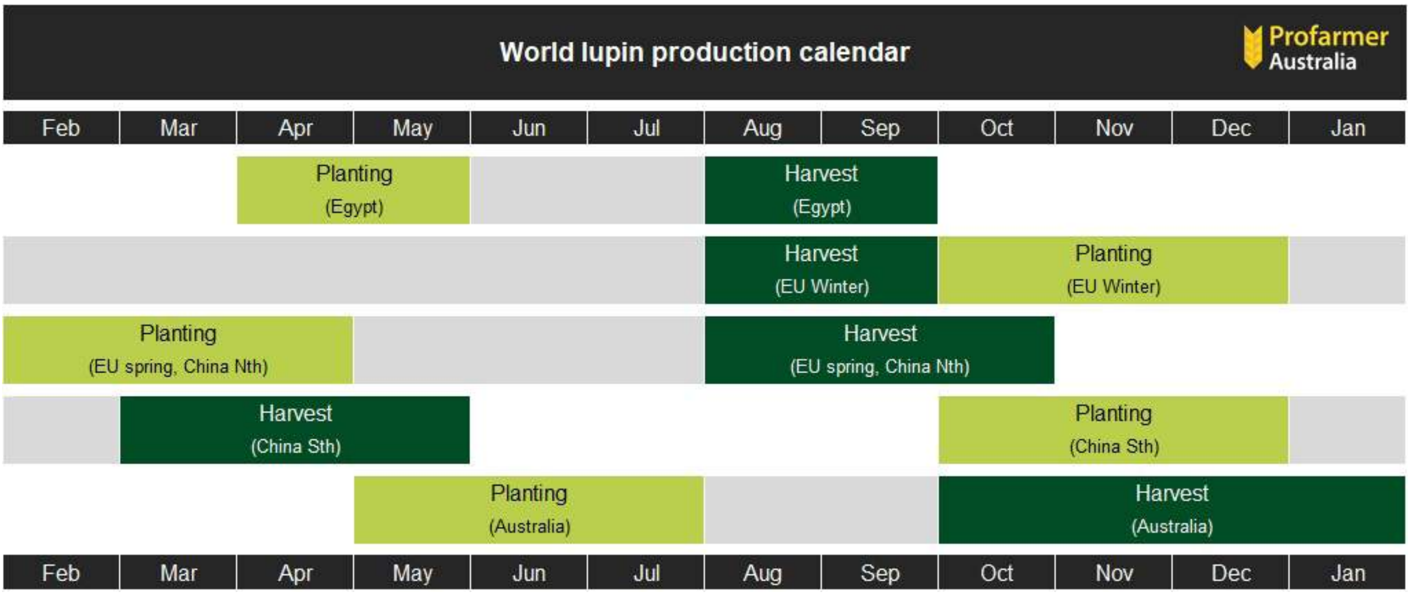


Figure 21: *Global lupin production calendar*

Some of the local influences on Australian lupin pricing are listed below:

1. Domestic production of each Lupin variety.
2. Availability and quality of local protein feeds.
3. Seasonal conditions and the subsequent demand for feed grain. Appetite for feed grains, including protein feed can vary greatly in the northern growing regions depending on seasonal conditions. Drought has seen sharp increases in appetite for the Sweet lupin variety as graziers and feedlotters are required to increase the volumes of feed they purchase.

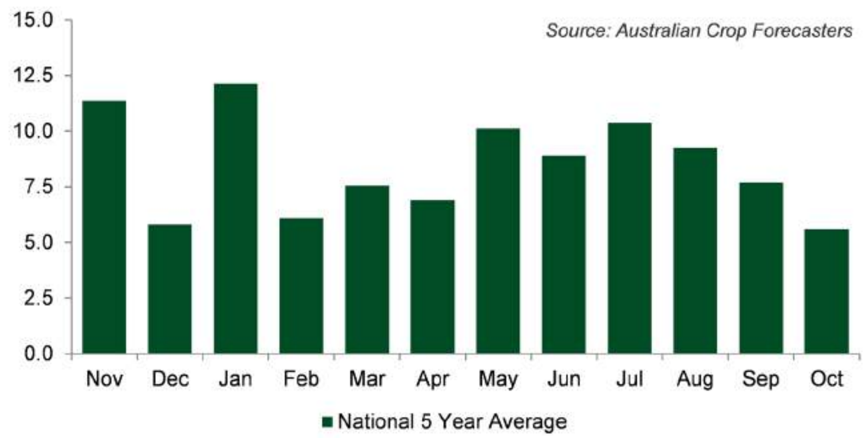


Figure 22: *5 year average monthly lupin export pace ('000 t)*

Note to figure: Australian lupin exports are usually strongest shortly after our harvest as buyers seek to move crop to fulfil immediate appetite.

15.2.2 Ensuring market access for Northern lupins

The market for the northern lupin crop varies greatly depending on the variety grown. Sweet lupins, which make up over 50% of the lupin production throughout NSW are typically absorbed within the local domestic feed complex as stockfeed. On-farm storage allows greater flexibility in accessing this market when it is most favourable to the grower and remains popular given the favourable nature that lupins store.

Comparatively Albus lupins are ultimately bound for export for human consumption purposes, where Egypt remains the main buyer. Production in NSW is not large enough to warrant exporting in bulk vessels, which means the entire northern lupin export market is executed through the container or 'delivered' market. To ensure access to this market grain is required to be stored on farm or delivered directly to the 'packer' at the time of harvest.

Albus lupins that do not make the required specifications for export are able to be sold into the domestic feed market, with the same market access principles applied for Sweet lupins to be followed.

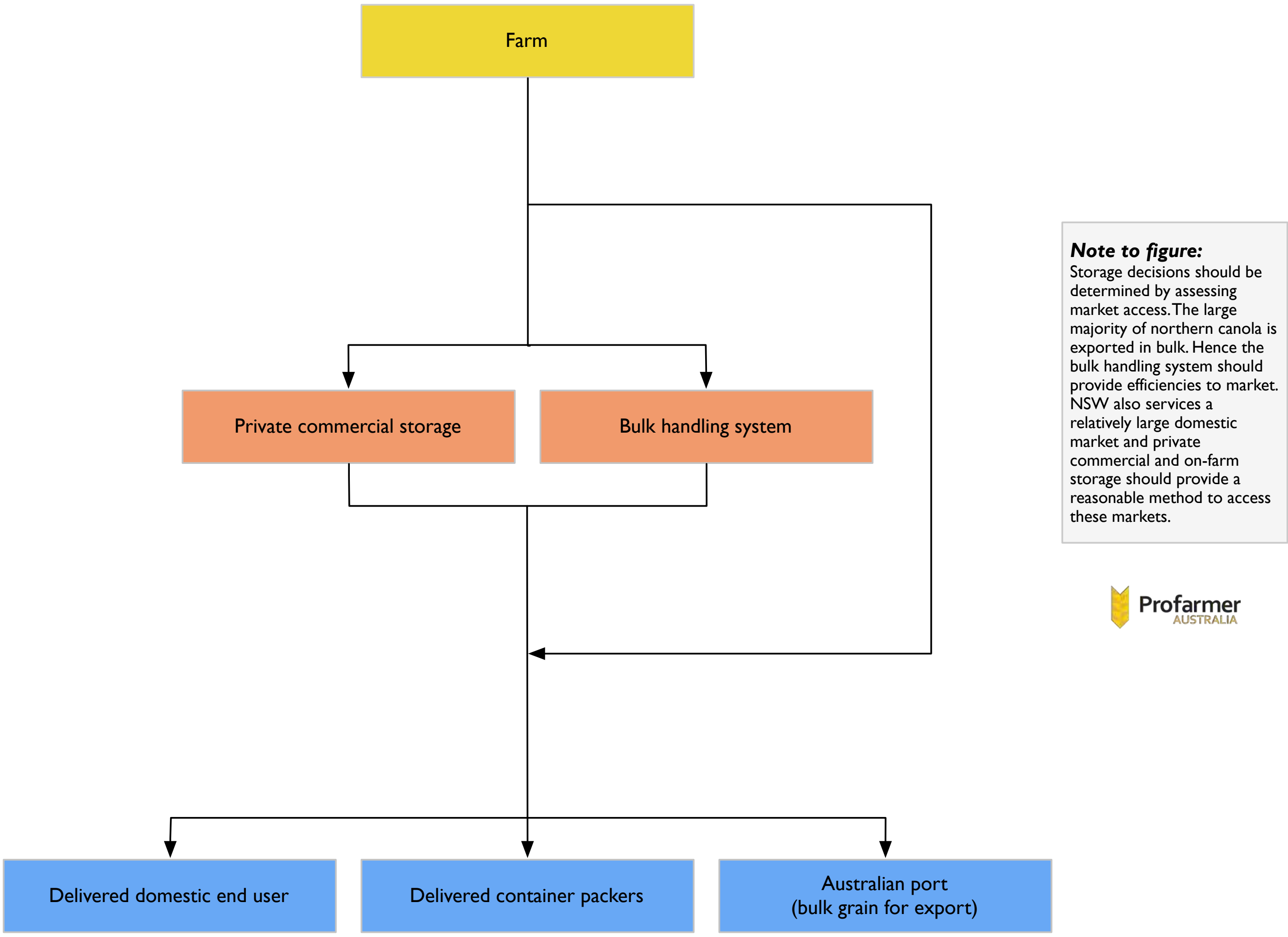


Figure 23: *Australian supply chain flow*

15.2.3 Executing tonnes into cash for Northern lupins

Given the volatile nature of lupins pricing, setting a target price using the principles outlined in section 1.2.2 minimises the risk of taking a non-profitable price or holding out for an unrealistically high price that may not occur. Pricing deciles for lupins are provided as a guide.

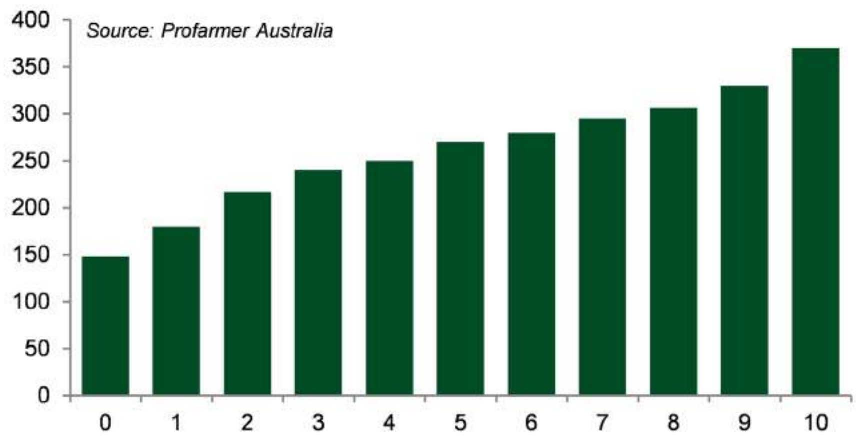


Figure 24: *Port Lincoln Lupin Deciles*

Selling options for lupins include:

1. Store on farm then sell - Most common occurrence, particularly for Sweet lupins. Lupins are safe to store and require less maintenance than cereal grains. It does however remain important to monitor quality, particularly for Albus variety lupins which will be required to meet export specification requirements. Must consider cost of storage in target pricing.
2. Cash sale at harvest - least preferred option as buyer demand does not always coincide with harvest. This is particularly true for Albus variety lupins where there are limited buyers and an influx of grower selling can pressure values lower.
3. Warehouse then sell - this provides flexibility for sales if on farm storage is not available. Must consider warehousing costs in cost of production and target prices. The availability to warehouse lupins in the northern region is limited, with the major bulk handlers not providing this service due to the low volumes of production in the region. Hence this may not be an option readily available to many growers within the Northern region.

There are some forward price mechanisms available for lupins with traditional fixed volume forward contracts and less commonly area contracts. Whilst area based contracts tend to price at a discount to fixed volume contracts, this discount needs to be weighed up against the level of production risk inherent in each contract.

As with all sales, counterparty risk and understanding contract of sale is essential. Counterparty risk considerations is especially important for pulse marketing as there is often a higher risk of contract default in international pulse markets than for canola or cereals due to the markets they are traded into and lack of appropriate price risk tools (such as futures). This can place extra risk on Australian based traders endeavouring to find homes for your product.

MORE INFORMATION

http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#world-pulse-production-calendar

http://www.pulseaus.com.au/marketing/pulse-traders

http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#lupin

http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide#marketing,-enduses-and-standards

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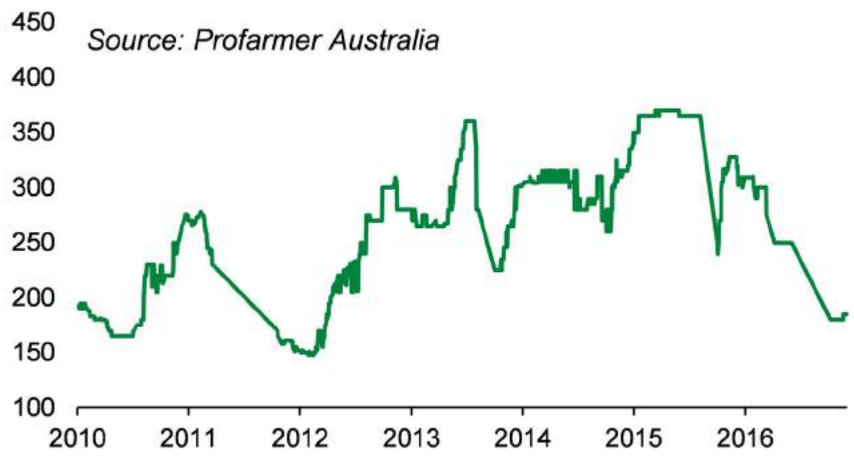

Figure 25: *Long term Port Lincoln Lupin price history.*

Current and past research

Project Summaries
www.grdc.com.au/ProjectSummaries

As part of a continuous investment cycle each year the Grains Research and Development Corporation (GRDC) invests in several hundred research, development and extension and capacity building projects. To raise awareness of these investments the GRDC has made available summaries of these projects.

These project summaries have been compiled by GRDC's research partners with the aim of raising awareness of the research activities each project investment.

The GRDC's project summaries portfolio is dynamic: presenting information on current projects, projects that have concluded and new projects which have commenced. It is updated on a regular basis.

The search function allows project summaries to be searched by keywords, project title, project number, theme or by GRDC region (i.e. Northern, Southern or Western Region).

Where a project has been completed and a final report has been submitted and approved a link to a summary of the project's final report appears at the top of the page.

The link to Project Summaries is www.grdc.com.au/ProjectSummaries

Final Report Summaries
http://finalreports.grdc.com.au/final_reports

In the interests of raising awareness of GRDC's investments among growers, advisers and other stakeholders, the GRDC has available final reports summaries of projects.

These reports are written by GRDC research partners and are intended to communicate a useful summary as well as present findings of the research activities from each project investment.

The GRDC's project portfolio is dynamic with projects concluding on a regular basis.

In the final report summaries there is a search function that allows the summaries to be searched by keywords, project title, project number, theme or GRDC Regions. The advanced options also enables a report to be searched by recently added, most popular, map or just browse by agro-ecological zones.

The link to the Final Report Summaries is http://finalreports.grdc.com.au/final_reports

Online Farm Trials
http://www.farmtrials.com.au/

The Online Farm Trials project brings national grains research data and information directly to the grower, agronomist, researcher and grain industry community through innovative online technology. Online Farm Trials is designed to provide growers with the information they need to improve the productivity and sustainability of their farming enterprises.

Using specifically developed research applications, users are able to search the Online Farm Trials database to find a wide range of individual trial reports, project summary reports and other relevant trial research documents produced and supplied by Online Farm Trials contributors.

The Online Farm Trials website collaborates closely with grower groups, regional farming networks, research organisations and industry to bring a wide range of crop research datasets and literature into a fully accessible and open online digital repository.

Individual trial reports can also be accessed in the trial project information via the Trial Explorer.

The link to the Online Farm Trials is http://www.farmtrials.com.au/

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