

GROWNOTES™

LUPIN

PLANNING/PADDOCK PREPARATION

PLANTING

PLANT GROWTH (PHENOLOGY)
AND DEVELOPMENT

NUTRITION, FERTILISER AND
BENEFITS IN THE ROTATION

WEEDS MANAGEMENT
AND HERBICIDE USE

CONTROL OF PESTS AND INSECTS

ROOT DISEASES AND NEMATODES

FOLIAR DISEASES

DESICCATION, CROP-TOPPING
AND GREEN/BROWN MANURING

HARVEST

GRAIN MARKETS

LUPIN AS A FEED SOURCE

GRAIN MARKETING

CURRENT RESEARCH

GRDC AND INDUSTRY CONTACTS

Start here for answers to your immediate lupin crop management issues



What variety of lupin should I grow?



What paddock conditions suit lupin?



What fertilisers do I require?



Are there specific weed control issues?



Are the diseases of lupin manageable?



What are the essentials before and during harvest?

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DPIRD 'Guide to Growing Lupins': <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

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GRDC Project Summaries: <https://grdc.com.au/research/projects>

Introduction

A.1 Crop overview

Western Australia is the nation's biggest producer and exporter of lupin grain, which is estimated to be worth about \$120-150 million to the State's economy annually.

About 632,000 tonnes of lupin grain were harvested in WA in 2015, making this the State's highest volume pulse crop and about 80 percent of total national production.¹ The Australian Government Department of Agriculture and Water Resources' Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) forecasts that WA will produce 545,000 t of lupin grain in 2016-17 from about 361,000 hectares (an 11 percent increase in area from 2015-16).²

Lupin is uniquely suited to the acid and sandy soils found across large tracts of WA's grainbelt and has a key role in breaking cereal disease cycles and adding fixed nitrogen (N) to soil for broadacre cropping systems.

Early research into lupin production by Dr John Gladstones at The University of Western Australia (UWA) in 1954 and application of the crop in sandplain areas by Sir Eric Smart at Mingenew led to significant tracts of previously unproductive soils being opened up for crop and cereal production in WA.

This was the forerunner to the highly successful modern wheat:lupin cropping system.

A.2 Types of lupin grown in WA

A.2.1 Narrow leafed lupin



Figure 1: *Narrow leafed lupin makes up the bulk of Western Australian lupin plantings.*

(SOURCE: GRDC)

1 Pulse Australia (2015-16) Australian Sweet Lupin Production 2010-11 to 2015-16, <http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#lupin>

2 ABARES (2016) Australian Crop Report: September 2016 No.179, ABARES, http://www.agriculture.gov.au/abares/publications/display?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pb_aucrd9aba_20160913_NmxJS.xml

Narrow leaved lupin varieties (*Lupinus angustifolius*), also known as Australian sweet lupin, make up about 95 percent of production in the western region.

In 2016, Pulse Australia estimated 353,000 ha of WA farming land was sown to narrow leaved lupin and expected grain production was 611,500 t.³

The Geraldton port zone had the highest estimated plantings of these varieties, at 180,000 ha, followed by Kwinana West at 100,000 ha, Albany at 39,000 ha, Kwinana East at 25,000 ha and Esperance at 9000 ha.⁴

Breeding advances by the Department of Primary Industries and Regional Development (DPIRD) – formerly the Department of Agriculture and Food Western Australia (DAFWA) – have led to the development of narrow leaved lupin with better environmental adaptation, yield potential, disease resistance (including to anthracnose) and resistance to the phomopsis fungus that causes lupinosis in grazing animals.

Australian Grain Technologies (AGT) has taken DPIRD’s successful lupin breeding program forward from 2016. It will continue to develop varieties that deliver higher returns to growers through improved yields, disease resistance, adaptation, herbicide tolerance and seed quality.

i MORE INFORMATION

Pulse Australia’s latest Australian Pulse Crop Forecasts can be found at: http://pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf

A.2.2 Albus lupin



Figure 2: Albus lupin is grown in Western Australia, mainly for export.

(SOURCE: GRDC)

Albus lupin (*L. albus*), also known as European white lupin, was grown in WA prior to anthracnose disease outbreaks in the mid-1990s.

In the past decade, new varieties with anthracnose resistance have been released, but this remains a minor crop in this State.

Pulse Australia estimated there were 7500 ha sown to albus varieties in the western region in 2016 and expected grain production was 13,600 t.⁵

The Geraldton port zone had an estimated 5500 ha sown to albus lupin and the Kwinana West port zone had the balance of 2000 ha.⁶

3 Pulse Australia (June 2013) Australian Pulse Crop Forecast, http://pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf
 4 Pulse Australia (June 2013) Australian Pulse Crop Forecast, http://pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf
 5 Pulse Australia (June 2013) Australian Pulse Crop Forecast, http://pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf
 6 Pulse Australia (June 2013) Australian Pulse Crop Forecast, http://pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf

i MORE INFORMATION

Pulse Australia's Lupin hub is at:
<http://www.pulseaus.com.au/growing-pulses/bmp/lupin>

A.2.3 Yellow and pearl lupin



Figure 3: Yellow lupin was popular in WA in the 1990s but production is now minimal.

(SOURCE: GRDC)

Yellow lupin (*L. luteus*) was popular during the 1990s when DPIRD – then DAFWA – researchers noticed it had high levels of resistance to common diseases and good tolerance of very acid soils. But only small areas are now sown to this species.

DPIRD is currently investigating the potential for high oil content pearl lupin (*L. mutabilis*) to be grown in parts of WA for grain production.

A.2.4 WA blue lupin



Figure 4: WA blue lupin is considered a weed in most areas of the State.

(SOURCE: GRDC)

WA blue lupin (*L. cosentinii*), or sandplain lupin, retains the wild lupin characteristics of bitter seed, hard-seededness and shattering pods.

This is considered to be a weed by lupin and other grain growers, with seed contaminating narrow leaved lupin crops and plants being a potential source of anthracnose.

But WA blue lupin is part of pasture systems in some western parts of the northern agricultural zone.

i MORE INFORMATION

DPIRD Guide to Growing Lupins:
<https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

A.3 Production history in WA

The area sown to lupin crops in WA increased during the three years to 2016, after a steady decline since the late 1990s due to weed and disease issues and low grain prices.

Many growers substituted lupin in the crop sequence with more profitable canola, more cereals or even a fallow in low rainfall areas.

DPIRD estimates WA lupin production fell from a peak of 1.5 million tonnes in 1999 to a low of just over 200,000 t in 2006, as can be seen in Figure 5.

Figure 5: Western Australian lupin area and production 1994-2015



(SOURCE: DAFWA)

Since the release of the first fully domesticated Australian sweet lupin in the late 1960s, lupin breeding by DPIRD has resulted in a doubling of average lupin yields from 0.7 to 1.5 t/ha in WA.⁷

But lupin crops grown on good sandplain country, especially in the northern agricultural region, can produce average yields of about 3 t/ha (similar to wheat yields in those areas).

A.4 Markets

WA narrow leaved lupin grain exports are mainly sold for use as animal feed to key markets in the European Union, Japan and Korea.

Lupin competes with soybeans in export markets and is typically valued at 70–75 percent of the price of soybean meal.⁸

It is estimated just under half of the State’s narrow leaved lupin grain production has historically been retained on-farm for use as stock feed or planting seed, or traded to domestic buyers.

There has been growing international interest in the use of lupin grain – processed to flour or flakes – for human consumption, as it is uniquely high in protein (30-40 percent) and dietary fibre (30 percent) and low in starch.

This means it has a low glycaemic index (GI) and could help to combat obesity and associated health problems of diabetes and heart disease.⁹

7 Pulse Australia (2015-16) Australian Sweet Lupin Production 2010-11 to 2015-16. <http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#lupin>

8 Pulse Australia website (2016) Pulses: Understanding Global Markets, <http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#lupin>

9 Pulse Australia website (2016) Pulses: Understanding Global Markets, <http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#lupin>

MORE INFORMATION

DAFWA Bulletin 102008 'Producing Lupins': <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

A.5 Key agronomic management factors to optimise lupin yields and profits in WA

A.5.1 Paddock selection

- Sandy textured soils with pH 4.5 – 7 (Calcium Chloride – CaCl₂) are ideal
- Avoid saline, waterlogging-prone, alkaline and shallow duplex soils
- Avoid soils with free lime present
- Ensure a relatively low weed burden
- Avoid paddocks close to big areas of WA blue lupin
- Retain stubble.

(SOURCE: DPIRD)¹⁰

A.5.2 Variety selection

- Consider soil/environment
- Assess disease risk
- Test seed for germination, seed size, vigour, presence of Cucumber mosaic virus (CMV) and anthracnose
- WA's newest narrow leafed varieties are PBA Jurien¹¹, PBA Leeman¹¹ PBA Barlock¹¹ and PBA Bateman¹¹
- WA's newest albus variety is Amira¹¹.

A.5.3 Sowing windows and conditions

- Sow as early as possible
- In the north, any time after mid-April
- In the south, from early May
- Don't sow after the first week of June in the north
- Dry sowing facilitates the longest growing season
- Dry sowing enables rapid crop establishment in warm soil
- Dry sowing can adversely affect simazine incorporation and weed control
- Dry sowing is best in paddocks with good stubble cover and low weed burdens
- Wet sowing (on a break of 15 millimetres over two days) improves crop germination
- Simazine can be washed into the soil by opening rains and improve weed control
- Delayed sowing until after the break allows the use of knockdown herbicides
- This is cost-effective and improves herbicide efficacy
- Delayed sowing reduces risks of a false break.¹¹

A.5.4 Sowing rate and depth

- Aim for plant density of 40-45 plants/square metre
- This will suppress weed growth, improve crop competition and optimise yields
- Higher plant densities reduce disease pressure
- Harvesting can be easier in dense crops
- Sow seeds 3-5 cm below the soil surface
- Deeper sowing (below 5 cm) can reduce incidence of pleiochaeta root rot
- Shallower sowing (2-3 cm) can reduce rhizoctonia hypocotyl rot disease
- Establishment tends to be uneven and weak when seed is sown below 7 cm.¹²

10 DPIRD website (2016) Lupin Essentials – growing a successful lupin crop, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

11 DPIRD website (2016) Lupin Essentials – growing a successful lupin crop, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

12 DPIRD website (2016) Lupin Essentials – growing a successful lupin crop, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

A.5.5 Inoculation

- Rhizobia are needed for nodulation and N fixation by lupin crops
- Inoculate seed with rhizobia when sowing lupin in a paddock for the first time
- Inoculate seed five years after the previous lupin crop on acid soils (pH below 6.5)
- Inoculate seed for every lupin crop on neutral and alkaline soils (pH above 6.5)
- Use a Group G or S inoculant.¹³

A.5.6 Weed control

- Effective weed control is essential for good yields
- Where practical, delay sowing to maximise weed kill from knockdown herbicides (especially where WA blue lupin is present)
- Incorporate pre-emergent simazine in wet soil if possible
- Ensure an even crop to optimise effectiveness of post-emergent herbicides
- Spray small weeds early
- Use highest registered rates of herbicides
- Crop-topping can be used when 80 percent of leaves have turned brown and/or fallen off lupin plants
- Implement cultural practices into integrated weed management plans
- Harvest weed seed capture and destruction can lower the weed seed bank.¹⁴

A.5.7 Insect control

- Check lupin crops for insects at critical development stages
- From emergence to three weeks, monitor Redlegged earth mites (*Halotydeus destructor*), cutworm (*Agrotis sp.*) and Lucerne flea (*Agrotis sp.*)
- At flowering, monitor aphids (*Aphididae*) and thrips (*Thysanoptera*)
- At pod fill, monitor native budworm (*Helicoverpa punctigera*)
- Adopt integrated pest management plans.¹⁵

A.5.8 Disease control

- Lupin roots, hypocotyls, stems, pods and seeds are susceptible to disease
- Manage with crop rotation, stubble retention, fungicide or pesticide application, variety selection and seed testing/treatment
- Reduce anthracnose risk by treating seed with a thiram-based seed dressing.¹⁶

A.5.9 Nutrition and fertiliser

- Use soil/plant tissue testing or paddock history to determine fertiliser rates
- Drill or band phosphate at seeding
- If needed, apply potassium within four weeks of sowing
- On potentially manganese (Mn)-deficient soils (mainly light sands), apply Mn super deep banded or as a spray when first pods are 2.5 cm.¹⁷

13 Pulse Australia website (2016) Pulses: Understanding Global Markets, <http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#lupin>

14 DPIRD website (2016) Lupin Essentials – growing a successful lupin crop, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

15 DPIRD website (2016) Lupin Essentials – growing a successful lupin crop, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

16 DPIRD website (2016) Lupin Essentials – growing a successful lupin crop, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

17 Pulse Australia website (2016) Pulses: Understanding Global Markets, <http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#lupin>

A.5.10 Harvest

- Harvest lupin crops when ripe
- Delays can reduce yields from lodging, pod shattering/drop or cracked grain
- Start harvest when grain moisture content reaches 14 percent
- Harvest when humidity is high and temperatures not extreme
- Harvest as quickly as possible
- Set the harvester drum or rotor speed to a minimum
- Open the concave relatively wide
- Store any harvested grain at an average moisture content of 20 degrees Celsius.¹⁸

A.6 Keywords

Lupin, pulse, narrow leaved lupin, albus lupin, pearl lupin, yellow lupin, western region, crop rotations, nitrogen fixing

¹⁸ DPIRD website (2016) Lupin Essentials – growing a successful lupin crop, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

 MORE INFORMATION

DPIRD lupin hub: <https://www.agric.wa.gov.au/lupins/lupin-western-australian-farming>

GRDC Hot Topic 'Break crop research': <https://grdc.com.au/Media-Centre/Hot-Topics/Break-crop-research>

Planning/paddock preparation

1.1 Crop overview

Including lupin in crop rotations with cereals can be more profitable than continuous cereal production in parts of Western Australia.

Other benefits include providing a cereal disease and pest break, increasing supplies of organic soil nitrogen (N), opening up more options for weed control and providing livestock feed in mixed farming systems.

Lupin effectively fix atmospheric N in symbiosis with bacteria and can take up phosphorus (P) efficiently from the soil.

Trial data collected from across WA's grainbelt by the Department of Primary Industries and Regional Development (DPIRD) – formerly the Department of Agriculture and Food Western Australia (DAFWA) – since the 1960s shows that growing continuous wheat crops in this State is rarely as productive or economically viable as rotations that include break crops, such as lupin, or pasture.

The data shows that yields from wheat following lupin crops average 0.6 tonnes per hectare higher than wheat crops following wheat and this can be higher if there are limiting factors such as root diseases or take all.¹

An analysis of 167 crop sequence trials in WA shows that wheat crops following fallow have an average 0.3 t/ha yield advantage over continuous wheat.² Recent research in WA is also finding that there are soil N and wheat yield benefits from including summer-sown serradella (and potentially biserrula, gland clover and bladder clover) in rotations, especially in medium to high rainfall areas and on acid soils.³

In the early years of the State's lupin industry, lupin-cereal rotations (with these crops grown in alternate years) were very common and are still practiced on some sandplain soils.

But in recent years, high canola prices have seen the oilseed replace lupin crops in many areas and, in some regions, cereal sequences have been extended.

Newer lupin varieties released for WA, including PBA Leeman[®], PBA Jurien[®] and PBA Barlock[®], have superior tolerance to the herbicide metribuzin (a Group C triazinone) which opens-up a wider range of weed control options in this phase of the rotation than has been previously possible.

Common cereal diseases and pests, including take-all, crown rot, common root rot, Septoria, Yellow spot, Barley yellow dwarf virus, rusts, mildew, some Root lesion nematodes (RLN) and Cereal cyst nematode (CCN), are not hosted by lupin plants.

This means a wheat crop grown after lupin tends to be less affected by these diseases and pests than if grown after wheat.

Lupin crops require a large amount of N for growth and obtain most of this from the atmosphere through symbiotic N fixation with rhizobia.

- 1 Seymour, M, Kirkegaard, J, Peoples, M, White, P, French, R (2012) Break crop benefits to wheat in Western Australia – insights from over three decades of research, *Crop and Pasture Science*, <http://www.publish.csiro.au/cp/CP11320>
- 2 Seymour, M, Kirkegaard, J, Peoples, M, White, P, French, R (2012) Break crop benefits to wheat in Western Australia – insights from over three decades of research, *Crop and Pasture Science*, <http://www.publish.csiro.au/cp/CP11320>
- 3 Loi, A (2014) Summer serradella emerging as a viable legume option, *Ground Cover Issue 113: Nov-Dec 2014*, GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-113-NovDec-2014/Summer-serradella-emerging-as-a-viable-legume-option>

After the crop is harvested, some of this N remains behind in the paddock as decaying roots, fallen leaves and stubble and – over time – becomes available to subsequent crops.

Typically, the higher the lupin yield, the more N is retained in the paddock and this more than compensates for the amount of N exported in the lupin grain.

DPIRD modelling has shown a 1.5 t/ha lupin crop can add about 60 kilograms/ha of soil N. This would provide about 25 kg/ha of available N to the following crop, which is the N equivalent to 52 kg/ha of urea fertiliser and sufficient to produce about 0.5 t/ha of wheat.⁴

MORE INFORMATION

Pulse Australia lupin variety information: www.grdc.com.au/Research-and-Development/Major-Initiatives/PBA/PBA-Varieties-and-Brochures

NVT Sowing guides: <http://www.nvtonline.com.au/crop-guides/sa/>

1.2 Lupin varieties in the western region

- Variety choice depends on farm location and disease risk
- Test seed for germination, vigour, seed size, disease presence
- Most recent WA narrow leafed varieties are PBA Leeman[®], PBA Jurien[®], PBA Barlock[®] and PBA Gunyidi[®]
- Newest WA albus variety is Amira[®]
- Pearl lupin may have potential in WA in future.

There are predominantly two types of lupin produced across southern Australia, each with separate growth requirements and end-uses.

Australian sweet lupin, or narrow leafed lupin (*Lupinus angustifolius*), is the main species grown in WA, which is the nation's biggest lupin producing State.

It is highly suited to the acidic, sandy or low fertility soils of the western region, where other pulses may grow poorly.

The albus lupin (*L. albus*), or European white lupin, is grown across all three Australian grain growing regions, including parts of WA, but in much smaller areas.

Albus varieties are best suited to fertile, well-drained, medium to heavy soils and show slightly better adaptation than narrow leafed varieties to alkaline soils.

There are several other lupin species that have been considered for broadacre production in WA, including:

- » Blue (sandplain) – lupin (*L. cosentinii*) – limited use in some areas for summer grazing; a weed to grain growers
- » Yellow lupin (*L. luteus*) – trialed in WA, not grown extensively
- » Atlas lupin (*L. atlanticus*) – not grown commercially
- » Hairy lupin (*L. pilosus*) – not grown commercially
- » Pearl lupin (*L. mutabilis*) – being tested for adaptation in WA.

Australian narrow leafed and albus lupin varieties have been developed in national collaboration through Pulse Breeding Australia (PBA).

Key agronomic traits and disease resistance status of the varieties commonly grown in WA are outlined in Table 1.

⁴ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

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Table 1: Lupin variety agronomic and disease guide

Variety	Flowering time	Height	Lodging	Pod Shattering	Drought Tolerance	Aphid Resist	Brown Leaf Spot	Pleiochaeta root rot	CMV seed transmit	Anthraxnose	Phomopsis – Stem	Phomopsis – Pod
Narrow leafed												
Jenabillup [Ⓟ]	M	T	MR	MS	MR	MR	MRMS	R	MRMS	S	MS	R
Coromup [Ⓟ]	E					R	MS		R	MR	R	R
Mandelup [Ⓟ]	VE	T	MS	MS	MR	R	MS	R	MS	MR	R	MRMS
PBA Barlock [Ⓟ]	E	M	MR	R		R	MS		RMR	R	MR	R
PBA Gunyi [Ⓟ]	VE	M	MS	R	MR	R	MS	R	MRMS	MR	R	R
PBA Jurien [Ⓟ]	VE	T	MS	MR		R	MS		MRMS	R	R	MR
PBA Leeman [Ⓟ]			MSMR	MR		R	MS		MRMS	MR	R	R
Wonga	E-M	M	MR	R	MS	R	MS	R	R	R	R	R
Albus lupin												
Amira [Ⓟ]	E	S-M	MR							MR		
Andromeda [Ⓟ]	M-L	M-T	MR							MS		

Flowering time; VE=very early, E=early, M=mid, L=late

Height; S=short, M=medium, T=tall

Lodging and disease reactions; R = Resistant RMR = Resistant to moderately resistant MR = Moderately resistant

MRMS = Moderately resistant to moderately susceptible MS = Moderately susceptible MSS = Moderately susceptible to susceptible

S = Susceptible SVS = Susceptible to very susceptible VS = Very susceptible.

(SOURCE: Agriculture Victoria: agriculture.vic.gov.au/_data/assets/word_doc/0009/318879/Lupin-2016.docx)

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The agricultural areas of WA that are suited to lupin production are shown in Figure 1.

These have been split into eight zones, each having broadly similar farming systems and production constraints that require similar management. Advisers can help to determine the parts of these zones that are more suited to lupin production than others and can recommend suitable lupin types and varieties for specific environmental and soil conditions.

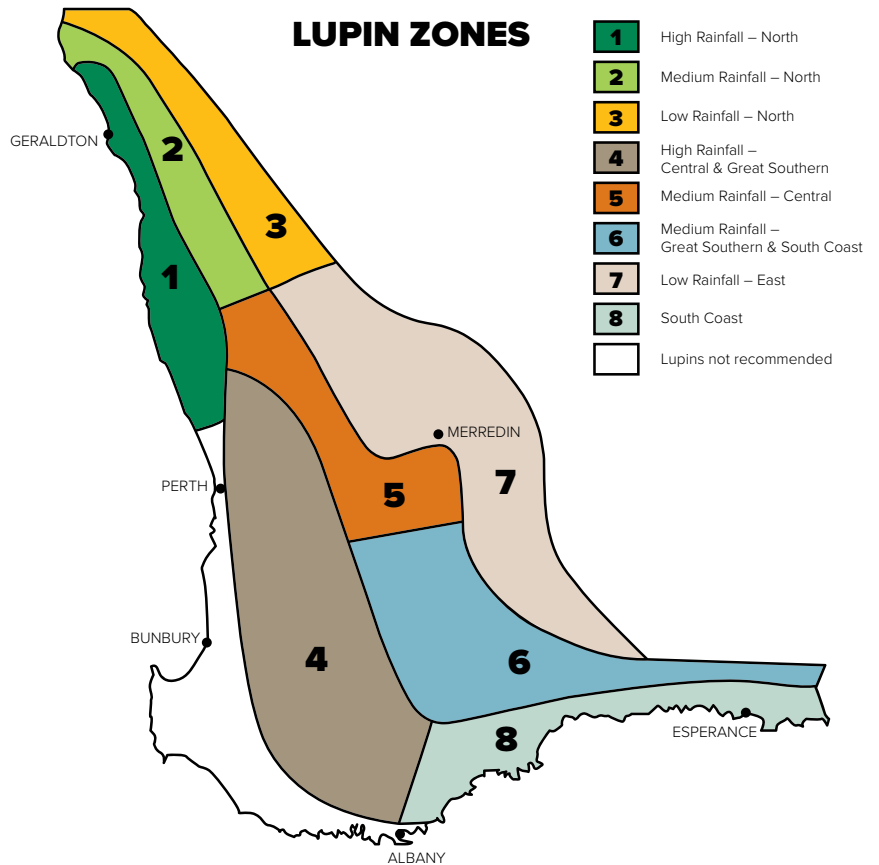


Figure 1: Lupin production zones in Western Australia.

(SOURCE: DAFWA)

i MORE INFORMATION

GRDC PBA Leeman[®] variety brochure: <http://www.grdc.com.au/Research-and-Development/Major-Initiatives/PBA/PBA-Varieties-and-Brochures>

1.2.1 Narrow leafed lupin varieties grown in WA

PBA Leeman[®]



Figure 2: The new variety PBA Leeman[®] is high protein and expected to be available for planting in 2018.

(SOURCE: PBA/GRDC)

- Bred by the PBA Lupin Breeding Program, led by DPIRD
- Released in September 2017 under PBA through Seednet
- Seed should be available for planting in 2018
- High protein – average 0.6 percent higher than Coromup[®]
- Good resistance levels to stem phomopsis and anthracnose
- Very tolerant to metribuzin
- Good pod shatter resistance – similar to PBA Gunyidi[®] and better than Mandelup[®]
- Highly suited to AgZones 1, 2, 3, 5
- Updated yield data from 2016 trials to be released in 2017.

(SOURCE: Seednet)

i MORE INFORMATION

GRDC outlines development of PBA Jurien[®] at: <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-118-Sep-Oct-2015/Whats-new-in-pulses-for-planting-in-2016>

PBA Jurien[®]



Figure 3: *The narrow leaved PBA Jurien[®] is a recently released lupin variety in Australia.*

(SOURCE: GRDC)

- Released 2015
- High yielding in most regions of WA and Australia
- Touted as Mandelup[®] replacement in WA
- Resistant to anthracnose (equivalent to PBA Barlock[®])
- Resistant to phomopsis (equivalent to PBA Gunyidi[®])
- Tolerant to metribuzin (superior to PBA Barlock[®], similar to Coromup[®])
- Early flowering
- Early maturing
- Seed size similar to Mandelup[®]
- Seed weight 10-17 g/100.

The narrow leaved PBA Jurien[®] is one of the most recently released lupin varieties in Australia, originating from the PBA Lupin Breeding Program, led by DPIRD in WA and tested as WALAN2385.

It combines strong disease resistance (R) to anthracnose and phomopsis with superior yield potential over some current varieties in WA, including PBA Barlock[®] and PBA Gunyidi[®] – as shown in Table 2.

Table 2: 2014 Lupin variety yields (WA) – Adjusted trial yields expressed as % of the site mean

Lupin Zone	1	2	3	4	5	6	7	8	Overall
Coromup ⁵	81	90	87	73	88	85	89	69	84
Danja ⁵	81	98	80	77	84	81	91	73	85
Jenabillup ⁵	102	94	98	95	101	96	98	100	98
Mandelup ⁵	90	106	106	96	99	100	99	118	100
PBA Barlock ⁵	110	105	88	108	102	106	110	91	105
PBA Gunyidi ⁵	97	104	101	107	103	105	101	102	102
Tanjil ⁵	95	99	85	88	91	94	96	92	94
PBA Jurien ⁵	102	99	106	109	112	107	112	110	107
Site Mean	2.73	1.91	1.24	2.5	1.91	3.08	0.73	2.67	1.96

(SOURCE: Alan Meldrum, Pulse Australia 2014)⁵

PBA Jurien⁵ is a potential replacement for PBA Barlock⁵ in WA's AgZone 1 (high rainfall parts of the northern agricultural region) and for Mandelup⁵ in most other regions of this State.

This variety is moderately susceptible (MS) to brown leaf spot and fungicide seed dressings are recommended, especially to reduce risks of seed-borne anthracnose infection.

It is moderately resistant (MR) to Cucumber mosaic virus (CMV) and Bean yellow mosaic virus (BYMV).

Its agronomic traits are similar to PBA Gunyidi⁵ and flowering time is slightly earlier than for PBA Barlock⁵.

PBA Jurien⁵ has good metribuzin tolerance and tolerance to pod shattering at harvest, but there is a slight risk of lodging in high-yielding situations.

In terms of grain quality, it has medium-large seeds with an alkaloid content similar to PBA Gunyidi⁵ that will meet market requirements.⁶

⁵ Meldrum, Alan (2014) Pulse Variety Performance. Pulse Australia, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Pulse-Variety-Performance-in-2014>

⁶ Pulse Breeding Australia (2016) PBA Varieties and brochures, www.grdc.com.au/Research-and-Development/Major-Initiatives/PBA/PBA-Varieties-and-Brochures

i MORE INFORMATION

GRDC's Ground Cover looks at the merits of PBA Barlock[®] at: <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-107-NovDec-2013/New-varieties-maintain-pulse-momentum>

PBA Barlock[®]



Figure 4: PBA Barlock[®] is a high yielding variety in WA.

(SOURCE: GRDC)

- Released 2013
- High yielding across WA
- Resistant to anthracnose
- Tolerant to metribuzin (equal to Mandelup[®])
- Moderately resistant to phomopsis stem blight
- Improved resistance to pod shattering over Mandelup[®]
- Early to mid-flowering
- Early maturity.

PBA Barlock[®] was tested in WA as WALAN2325 and is suitable to replace Mandelup[®], Tanjil[®] and Wonga in most lupin growing areas of WA.

It is particularly well adapted to the high and medium rainfall zones of the State's northern agricultural regions.

PBA variety trials have shown a 2-3 percent yield advantage over the traditionally popular variety Mandelup[®] and up to 12 percent higher yields than Tanjil[®] in most areas of WA. This is illustrated in the 2014 results shown in Table 2.

PBA Barlock[®] has considerably more metribuzin tolerance than the older WA varieties, allowing more options for weed control in-crop.

Strong anthracnose resistance makes PBA Barlock[®] the best variety choice in AgZone 1 and, in all regions, seed dressing is recommended to reduce risks of seed-borne infections.

This variety is MS to brown leaf spot, but MR to CMV seed transmission.

It has shown similar herbicide tolerance to Mandelup[®] and has less risk of pod shattering at harvest. Seed size is similar to Tanjil[®] and protein levels are similar to Mandelup[®].⁷

⁷ Pulse Breeding Australia (2016) PBA Varieties and brochures, www.grdc.com.au/Research-and-Development/Major-Initiatives/PBA/PBA-Varieties-and-Brochures

PBA Gunyidi[®]



Figure 5: PBA Gunyidi[®] has good resistance to pod shattering.

(SOURCE: GRDC)

- Released 2010
- Slightly later flowering and maturing than Mandelup[®]
- Shorter stem
- Resistant to phomopsis stem blight
- Moderately susceptible to brown leaf spot
- Moderately resistant to CMV seed transmission
- Moderately resistant-resistant to anthracnose
- High resistance to pod shattering
- Good lodging resistance.

PBA Gunyidi[®] tends to be higher yielding than Mandelup[®] in all WA lupin production zones.

As found in the PBA variety trial results from 2014, shown in Table 2, it has clear advantages in the AgZones 1, 4, 6 and 7.

This variety is early flowering and maturing, with high resistance to pod shattering at harvest, which reduces risks of yield loss if harvest is delayed.

PBA Gunyidi[®] has good tolerance to commonly used herbicides, including metribuzin, and varied resistance levels to aphids, anthracnose and phomopsis stem blight. It is mildly susceptible to brown leaf spot.⁸

⁸ Pulse Breeding Australia (2016) PBA Varieties and brochures, www.grdc.com.au/Research-and-Development/Major-Initiatives/PBA/PBA-Varieties-and-Brochures

Jenabillup[®]



Figure 6: *Jenabillup[®] is a good variety for WA's high rainfall areas.*

(SOURCE: GRDC)

- Released 2007
- Slightly later flowering than Mandelup[®]
- Moderately resistant to BYMV
- Less suited to crop-topping than Mandelup[®]
- Susceptible to anthracnose
- Less tolerant of metribuzin.

Jenabillup[®] remains a good variety choice for lupin production in WA's high rainfall areas, especially in AgZone 8, due to its BYMV resistance levels (it is MR).

As shown in Table 2, it out-yielded PBA Barlock[®] in 2014 variety trials in this zone. This variety is mid-maturing, which suits areas with a longer growing season, as the extended flowering window can assist with boosting yield. But this factor makes it less suitable for crop-topping.

Jenabillup[®] is MR for black pod syndrome and brown leaf spot and MR for seed transfer of CMV.

Coromup[®]



Figure 7: Coromup[®] is an older variety released for WA's medium and low rainfall areas.

(SOURCE: GRDC)

- Released 2006
- Aimed at WA medium and low rainfall zones
- High protein and grain quality
- Early maturing
- Good resistance to anthracnose and phomopsis stem blight
- Metribuzin tolerance similar to Mandelup[®].

Coromup[®] was released in 2006 as a high quality narrow leaved variety for WA's medium and lower rainfall zones, but has largely been replaced by newer lines.

It has high seed protein – 2.4 percent higher than Mandelup[®] – and a good disease resistance and herbicide tolerance profile.

Coromup[®] is early maturing but tends to be susceptible to lodging in high rainfall areas.

Mandelup[®]



Figure 8: Mandelup[®] has mostly been replaced in WA with newer varieties.

(SOURCE: GRDC)

- Released 2005
- Good early vigour and harvest height
- Early flowering
- Suits heavy soil types
- High phomopsis resistance
- Anthracnose and aphid resistant
- Tolerant to metribuzin
- Good seed protein.

Mandelup[®] is widely adapted and has been a consistently high yielding variety in many WA AgZones in recent years, but is now largely replaced by newer varieties.

Its early maturity makes it suitable for crop-topping for weed management and it has good metribuzin tolerance.

This variety is not recommended for high rainfall areas, as it has a tendency to lodge in high productivity.

It has also experienced problems with pod shatter if there is a delayed harvest and can have poorer seed germination rates than some other varieties in some years.

Quilnock[®]



Figure 9: *Quilnock[®]* has mostly been replaced in WA.

(SOURCE: GRDC)

- Released 2001
- Suited to medium and low rainfall areas
- Some brown leaf spot resistance
- Moderate resistance to CMV
- Susceptible to anthracnose
- Prone to lodging in high rainfall areas.

At its release, Quilnock[®] was suited to WA's central and eastern grainbelt, where risks of disease – such as anthracnose – and lodging are low.

This variety has largely been replaced by newer varieties in WA.

Tanjil[®]



Figure 10: *Tanjil[®] is an older variety for WA with good anthracnose resistance.*

(SOURCE: GRDC)

- Released 1999
- Suited to high rainfall areas of WA's northern grainbelt
- Resistant to anthracnose
- Early maturing
- Low risk of lodging
- Sensitive to metribuzin.

Tanjil[®] is an older variety that was well suited to the northern grainbelt, with good anthracnose resistance and higher yields than the Wonga variety.

It has resistance to stem and pod phomopsis and aphids, with MR to CMV. But it is sensitive to metribuzin.

Wonga



Figure 11: *Wonga is an older variety for WA that has mostly been replaced.*

(SOURCE: GRDC)

- Released 1998
- Early-mid flowering
- Moderately yielding
- Resistant to anthracnose and phomopsis
- Can be susceptible to brown leaf spot
- Sensitive to metribuzin.

Wonga is an early flowering, moderate yielding narrow leafed variety that is resistant to anthracnose and phomopsis.

It is suited to medium rainfall zones, but has largely been replaced by newer WA varieties. It does remain an option for disease and weed control in the lupin phase, but is sensitive to metribuzin.

i MORE INFORMATION

DPIRD guide to growing Amira[®]:
<https://www.agric.wa.gov.au/lupins/amira-anthraxnose-resistant-albus-lupin-western-australia?page=0%2C1>

1.2.2 Albus (or European white) lupin varieties in WA

Amira[®]



Figure 12: Amira[®] is a new albus variety that is early flowering.

(SOURCE: GRDC)

- High yielding
- Anthracnose resistant
- Mid-flowering, late maturing
- Similar grain size and quality to Andromeda[®] and Kiev Mutant.

Amira[®] was released in 2012 as a relatively early flowering variety that produces high yields in similar areas to where Kiev Mutant was popular before outbreaks of anthracnose in WA.

As indicated in Table 3, trials during the 2000s showed Amira[®] consistently produced about 20 percent higher yields than Andromeda[®] (released in 2005) and has been suggested as a replacement for that variety in WA.⁹

Table 3: Grain yield of Amira[®] in relation to other albus lupin varieties from Western Australian variety trials (2007-2010)

Variety	2007	2008	2009	2010	Overall Mean
Amira [®]	117	147	114	124	126
Andromeda [®]	100	100	100	100	100
Kiev Mutant	106	137	133	113	122
No.of trials	2	2	2	1	

(SOURCE: DAFWA)⁹

Amira[®] is well suited to medium rainfall areas of WA's northern grainbelt, where anthracnose pressure is not high

⁹ DPIRD (2016) Amira: an anthracnose resistant albus lupin for Western Australia, <https://www.agric.wa.gov.au/lupins/amira-anthraxnose-resistant-albus-lupin-western-australia?page=0%2C1>

¹⁰ DPIRD (2016) Lupin essentials – growing a successful lupin crop, DAFWA, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

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As shown in Table 4, Amira[®] is MR to anthracnose and has significantly better resistance to this disease than Andromeda[®], but crops may still require fungicide protection in high rainfall and high disease risk areas.¹¹

Table 4: Phenology and anthracnose ratings of albus lupin varieties

Variety	Flowering time	Maturity time	Plant Height	Lodging	Anthracnose
Amira [®]	early	mid-early	short-med	MR	MR
Andromeda [®]	mid-late	late	med-tall	MR	MS
Kiev Mutant	early	early	medium	MS	VS

MR = moderately resistant, MS = moderately susceptible, S = susceptible
(SOURCE: DAFWA)²

Herbicide tolerance trials in WA on red clay loam and red sandy loam soils show Amira[®] has good tolerance to herbicides commonly used in albus lupin production.

It has metribuzin tolerance similar to Andromeda[®] and Kiev Mutant.

Amira[®] is tolerant to aphids in WA conditions, but will be affected by native budworm (*Helicoverpa sp.*).

It is advised not to delay harvest for this variety, even though pods are unlikely to shatter or shed, to ensure seeds remain undamaged and are of high quality.

Amira[®] has large white seed similar to Kiev Mutant and will be accepted in human consumption markets. Its seed alkaloid content is lower than Andromeda[®] and protein content is similar to Kiev Mutant and Andromeda[®].¹³

11 DPIRD (2016) Amira: an anthracnose resistant albus lupin for Western Australia, <https://www.agric.wa.gov.au/lupins/amira-anthracnose-resistant-albus-lupin-western-australia?page=0%2C1>
 12 DPIRD (2016) Amira: an anthracnose resistant albus lupin for Western Australia, <https://www.agric.wa.gov.au/lupins/amira-anthracnose-resistant-albus-lupin-western-australia?page=0%2C1>
 13 DPIRD (2016) Amira: an anthracnose resistant albus lupin for Western Australia, <https://www.agric.wa.gov.au/lupins/amira-anthracnose-resistant-albus-lupin-western-australia?page=0%2C1>

i MORE INFORMATION

DPIRD guide to growing Andromeda[Ⓛ]: <https://www.agric.wa.gov.au/lupins/growing-andromeda-%E2%80%93-albus-lupin-variety-improved-tolerance-anthraxnose>

Andromeda[Ⓛ]



Figure 13: *Andromeda[Ⓛ] suits medium rainfall areas of WA.*

(SOURCE: GRDC)

- Released 2005
- Improved tolerance to anthracnose than Kiev Mutant
- Suits medium rainfall areas
- Suits loams and red soils
- Later flowering.

Andromeda[Ⓛ] is no longer widely grown in WA, but was the first anthracnose resistant albus variety to be released (as a replacement for Kiev Mutant) in this State in the past decade.

It could produce higher yields under high anthracnose pressure, but was consistently about 10 percent lower yielding than Kiev Mutant when disease severity was low.

DPIRD advises that Andromeda[Ⓛ] remains suited to some areas receiving about 350-400 mm annual rainfall and responds well to early sowing because it is later flowering.

It is also well suited to the fertile loams or clay loams that occur in valleys throughout WA and the red soils of the Mingenew, Mullewa and Morawa region, but will not grow well in infertile sands or duplex soils.

Andromeda[Ⓛ] seed contains 39 percent protein and 9 percent oil, both higher than narrow leafed lupin seed and seed from other pulse crops.

It has a lower alkaloid and crude fibre content than narrow leafed lupin and could be a useful stockfeed.¹⁴

¹⁴ DAFWA (2016) Growing Andromeda – an albus lupin variety with improved tolerance to anthracnose, <https://www.agric.wa.gov.au/lupins/growing-andromeda-%E2%80%93-albus-lupin-variety-improved-tolerance-anthraxnose>

Kiev Mutant



Figure 14: *Kiev Mutant was popular in WA in the 1990s but has been replaced with newer varieties.*

(SOURCE: GRDC)

- Released 1970s
- Redundant in WA.

Kiev Mutant was grown in WA's northern grainbelt and other parts of the State during the 1990s, but the variety disappeared when lupin anthracnose was identified in 1996. It was replaced by Andromeda[®] and, more recently, Amira[®].

1.2.3 Potential new lupin species for WA

Researchers have identified three alternative lupin species with potential for WA conditions:

- » Atlas lupin (*Lupinus atlanticus*)
- » Hairy lupin (*Lupinus pilosus*)
- » Pearl lupin (*Lupinus mutabilis*).

Atlas and hairy lupin types belong to the same rough-seeded group as WA blue – or sandplain – lupin and are adapted to fine-textured alkaline soils.

DPIRD plant breeders have fully domesticated both of these species, but breeding efforts have now stopped and to 2016 there was no commercial production in this State.

DPIRD indicates that pearl lupin are of more interest because of the high grain protein and oil content of this species, which is similar to soybeans (up to 45 and 18 percent respectively) and higher than other domesticated lupin species.

Field trials of advanced breeding lines of sweet pearl lupin types have been undertaken in WA, where it is thought these varieties may have a place on fertile soils and in environments that suit albus lupin.

A small breeding program was conducted by DPIRD researcher Jon Clements.

As part of this research, he worked with DPIRD's Mark Sweetingham and their trials found that pearl lupin was acid tolerant, but did not perform well on the classic deep sandy soils where narrow leafed lupin grows well.¹⁵

Their research indicated the pearl lupin lines were slightly more susceptible to lime-induced iron deficiency than narrow leafed lupin.

Field trials showed pearl lupin was most competitive in yield with other lupin species in medium to higher yielding regions with low anthracnose risk, such as the southern grainbelt.

Even in these regions, yields tended to be significantly lower than narrow leafed and albus lupin. These lines were less tolerant of triazine herbicides and could potentially require more weed control consideration.¹⁶

Glasshouse trials have found current pearl lupin germplasm is very susceptible to brown leaf spot, quite susceptible to anthracnose, requires fungicide seed treatment and would need to be grown in wide rotations.¹⁷

15 DPIRD (2016) Potential new lupin species for Western Australian Agriculture, <https://www.agric.wa.gov.au/lupins/potential-new-lupin-species-western-australian-agriculture>

16 Clements, J, Buirchell, B, Francis, G, Sweetingham, M (2006) Higher yielding elite lines of pearl lupin for Australian agriculture, CLIMA, UWA, DAFWA, http://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKewj_perO2lvPAhXTQD4KHQR-CpMQFqgbMAA&url=http%3A%2Fuwa.edu.au%2F_data%2Fassets%2Fword_doc%2F0019%2F920431%2FHigher_yielding_elite_lines_of_pearl_lupin_for_Australian_agriculture_Summary2.doc&usq=AFQjCNGo-sQ1-4-onH_6FpdvXk7d_JMjyQ&sig2=jtcVR2bGuovOc2kdVeJz5q&bvm=bv132479545,d.dGo

17 Sweetingham, M (2005) The potential of the pearl lupin (*Lupinus mutabilis*) for southern Australia, DAFWA, <http://finalreports.grdc.com.au/UWA00043>

i MORE INFORMATION

DPIRD Lupin essentials: <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

i MORE INFORMATION

WeedSmart 10-point plan: www.weedsmart.org.au

GRDC Integrated Weed Management hub: www.grdc.com.au/IWM

DPIRD Lupins essential guide: <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

1.3 Soil types and paddock selection

- Ideally sow in sandy textured soils with pH 4.5 – 7 (Calcium Chloride – CaCl₂) and good depth
- Avoid saline, waterlogging-prone, alkaline and shallow duplex soils
- Avoid soils with free lime or limestone
- Choose paddocks with a relatively low weed burden
- Avoid paddocks with big populations of WA blue lupin
- Ideally use paddocks with high stubble to reduce brown leaf spot risk
- Consider disease and weed burdens for rotation intervals.

Narrow leafed lupin varieties suit soils with low free lime levels (up to 4 percent) and will experience poor growth on hard setting or shallow soils (less than 25 cm) that prevent root penetration.

These varieties are most suited to acid soils with a pH of 4.5 – 7, formed with sand (or sand over clay) and well-structured loam soils.

Albus lupin is suited to medium to heavy, fertile and free-draining soils. These varieties are sensitive to waterlogging and grow poorly on sandy soils.

WA's newest albus variety, Amira[®], yields well on the fertile loams or clay loams that occur in valleys right across the grainbelt and on the red soils of the Mingenew, Mullewa and Morawa region. It has not performed well in infertile sands or duplex soils.

Amira[®] is adapted to soils of slightly higher pH than narrow leafed lupin, but will not grow well on loams and clays with a pH above 7.5 if these soils become saturated with water.

It is best to avoid, where possible, sowing albus lupin crops close to WA blue lupin infestations (such as along fence lines and in-paddock populations), as blue lupin can harbour anthracnose. Frost sensitivity can also be a problem in prone areas.¹⁸

1.4 Weed and herbicide considerations

- Summer and in-season weed control is vital to optimise lupin crop yields
- Consider herbicide residues when choosing lupin paddocks
- Where practical, delay sowing to maximise weed kill from knockdown herbicides (particularly in the presence of WA blue lupin)
- Apply suitable pre or post-emergent herbicides
- Ensure an even crop for post-emergent herbicide applications at correct stage
- Spray small weeds early for an effective kill
- Use highest registered rates of post-emergent herbicides (without crop damage)
- Use desiccation and/or crop-topping later in the season if necessary
- Consider harvest weed seed capture and destruction to run down weed seedbanks.

Paddock preparation for lupin starts in the summer, as crop germination and early growth can be adversely affected where Afghan melons (*Cucumis myriocarpus*) and paddy melons (*Citrullus lanatus*) and other weeds are present.

Lupin can be impacted by herbicide residues where rainfall has been minimal in both summer and the previous growing season.

This should be a consideration when planning lupin paddocks and crop sequences, as should the weed burden that could be left-over from the previous year if knockdown has not been possible.

¹⁸ DPIRD (2016) Lupin essentials – growing a successful lupin crop, DAFWA, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

i MORE INFORMATION

DPIRD Lupin essentials guide to paddock planning: <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

i MORE INFORMATION

DPIRD machinery and harvest tips: https://www.agric.wa.gov.au/lupins/amira-anthraxnose-resistant-albus-lupin-western-australia?page=0%2C2#smartpaging_toc_p2_s1_h3 and https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4#smartpaging_toc_p4_s2_h2

Consideration of the herbicide label for the active type and plant-back periods should be given, as well as soil pH and rainfall.

Lupin crops have particular sensitivity to group B sulfonamide residues and all pulses, including lupin, are vulnerable to some Group I residues.

An integrated weed management (IWM) plan that incorporates herbicide, cultural and physical measures will be most effective for suppressing weeds, lowering weed seedbanks and prolonging herbicide sustainability in WA lupin crops.¹⁹

1.5 Disease and pest considerations

- Test planting seed for presence and levels of anthracnose
- Use fungicide seed dressings where necessary
- If disease pressure high, use label rates of registered foliar fungicides
- Check crops from emergence to three-weeks for mites, cutworm and Lucerne flea
- Check for aphids at flowering
- Check for native budworm at pod fill.

Most modern narrow leafed and albus lupin varieties have reasonable disease resistance.

But it is recommended to have narrow leafed seed tested for CMV and anthracnose and albus seed tested for anthracnose.

Narrow leafed lupin is susceptible to Brown leaf spot and to avoid other viruses, sowing lupin adjacent to legumes or pastures is not recommended.

Most current varieties have phomopsis resistance, but significant rain on the plants while maturing or after harvest can prompt disease development.

Care should be taken if this occurs and there is intent to graze lupin stubbles or feed seed to stock. The aim is to avoid lupinosis in livestock in this situation.

If a paddock has a history of lupin disease, it may be best to rest or sow a different crop to allow for a disease 'break'.²⁰

1.6 Machinery considerations

- Aim for narrow leafed and albus plant density of 40 – 45 plants/m²
- This is a sowing rate of about 150 kg/ha for albus and 80-100 kg/ha for narrow leafed varieties
- Use sowing depth of 3-5 cm
- For albus, coarse metering wheels on air seeders can help avoid cracking the seed
- An agitator in the seed box can help albus seeds flow smoothly
- At harvest, set the harvester drum or rotor speed to a minimum and the concave opened quite wide
- For albus, harvest using wide wire concaves or remove alternate wires of a cereal concave
- Increase concave clearance if seed is being cracked
- Increase drum speed if seed is left in the pods
- Handle seed carefully after harvest to avoid damage.

The recommended plant density for narrow leafed and albus lupin crops in WA is 40 to 45 plants/m². This equates to a seeding rate of about 150 kg/ha for albus and 80-100 kg/ha for narrow leafed varieties.

¹⁹ DPIRD (2016) Lupin essentials – growing a successful lupin crop, DAFWA, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

²⁰ DPIRD (2016) Lupin essentials – growing a successful lupin crop, DAFWA, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

WA trials have shown optimum plant densities that will maximise yields change depending on location and season, but losses can be substantial if plant populations fall below 40 plants/m².²¹

Research has found that keeping lupin crop density high helps to suppress weed growth, boost crop competitiveness with weeds, reduce Brown leaf spot and CMV effects and allows the crop to compensate for any issues with poor establishment due to sandblasting, non-wetting soils and/or root diseases.²²

Successful lupin growing can often depend on equipment.

At seeding, augers have potential to damage grain and using tabulators – or belt elevators – may provide a possible solution.

Seeders need to be capable of sowing bigger lupin seed and modifications to seed tubes and dividing heads may be required, as well as the metering mechanisms.

At harvest, care is needed to avoid pod shattering as lupin grain enters the header from the cutter bar. This risk can be reduced by harvesting in high humidity and avoiding extreme heat.

For albus lupin, it is recommended to use wide wire concaves or remove alternate wires of a cereal concave because the seeds are large.

It is advised to start with the closest concave clearance and the slowest drum speed and then increase concave clearance if seed is being cracked.

Use higher drum speed if seed is left in the pods and carefully handle seed after harvest to avoid damage.

Machine cleaning may be necessary where there is evidence of certain diseases.²³

1.7 Seed quality and germination issues

If using lupin seed from WA or South Australia (SA), it must be tested for anthracnose (which only occurs in these two states) to avoid spread.

Grain being retained from harvest for subsequent sowing should be harvested first, where possible, to ensure best quality and germination rates.

Ideally, moisture levels should be below 14 percent at harvest.

The lupin seed embryo is very sensitive to impact if it becomes dry and brittle.

Research has found that even seed with no visible damage can have low percentage germination rates if it suffered a high impact when its moisture content was low.

Seed with moisture levels above 13 percent should not be stored in a steel silo after harvest. It may be advisable to dry the grain to ensure viability.²⁴

MORE INFORMATION

GRDC's Stored Grain information hub:
<http://storedgrain.com.au/>

²¹ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

²² White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

²³ DPIRD (2016) Lupin essentials – growing a successful lupin crop, DAFWA, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

²⁴ DPIRD (2016) Lupin essentials – growing a successful lupin crop, DAFWA, <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

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DPIRD hub 'Lupin essentials – Growing a successful lupin crop': <https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop>

DPIRD Bulletin 102008 'Producing Lupins': <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

DPIRD Diagnostic Laboratory Services (DDLS)-Plant Pathology (formerly AGWEST Plant Laboratories): <https://www.agric.wa.gov.au/ddls-seed-testing-and-certification>

Agriculture Victoria: <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/seed-health-testing-in-pulse-crops>

DPIRD seed testing hub: <https://www.agric.wa.gov.au/plant-biosecurity/seed-testing>

Plant Science Consulting: <http://www.plantscienceconsulting.com.au>

Primary Industries and Regions SA (PIRSA)/South Australian Research and Development Institute (SARDI) Seed and Plant Pathology testing Service: http://www.pir.sa.gov.au/research/services/crop_diagnostics/seed_and_crop_testing

FeedTest: www.feedtest.com.au

Planting

2.1 Overview

The ability of lupin and other legumes to fix their own nitrogen (N) make them an attractive break crop option in Western Australia.

But lupin require some specific soil types and seed quality, planting, inoculant, row spacing and seeding practices to ensure growers can take full advantage of this feature.

2.2 Seed quality and testing

- Always use high quality seed
- Test seed for vigour, germination weed seeds and disease
- Handle seeds carefully to protect from damage
- Tests for low manganese (Mn) and/or phosphorus (P) levels may be useful.

Poor quality seed can result in poor germination, less vigour and lower yields in WA lupin crops.

Quality of seed is affected by fungal or viral disease infection, physical damage (including from harvest practices, augers or bad weather) and low manganese (Mn) or phosphorus (P) levels.

Seed tests are available that can detect the most important seed-borne pathogens of lupin, especially anthracnose and Cucumber mosaic virus (CMV) in WA. Only pathogen-free seed should be used for sowing.

Testing can be carried out on lupin seed for: germination; vigour; thousand seed weight; Mn and P levels; and phomopsis.

Testing for purity – or weed seed contamination – can also be useful to reduce risks of introducing new weeds to paddocks and reducing reliance on herbicides.

2.2.1 Disease tests

Testing seed through an accredited laboratory before sowing will identify potential disease problems and help with risk management planning.

Lupin seed disease testing services for WA growers are available from:

- DPIRD Diagnostic Laboratory Services (DDLS) (formerly AGWEST Plant Laboratories) <https://www.agric.wa.gov.au/ddls-seed-testing-and-certification>
- Primary Industries and Regions SA (PIRSA)/South Australian Research and Development Institute (SARDI) Seed and Plant Pathology testing Service http://www.pir.sa.gov.au/research/services/crop_diagnostics/seed_and_crop_testing
- Plant Science Consulting <http://www.plantscienceconsulting.com.au>
- FeedTest www.feedtest.com.au
- Tasmanian Government TASAG ELISA Testing Service <http://dpiipwe.tas.gov.au/biosecurity/plant-biosecurity/plant-health-laboratories/tasag-elisa-testing>
- SGS Australia www.sgs.com.au

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GRDC Tips and Tactics: Legume N fixation: <https://grdc.com.au/tt-legume-n-fixation>

Disease tests typically require one kilogram of seed and will identify the common pathogens found in WA lupin crops that cause anthracnose, CMV, phomopsis stem blight and sclerotinia stem rot.

Results show the amount of disease inoculum in terms of:

- » Proportion of infected seeds
- » Degree or severity of infection (inoculum per individual seed)
- » Viability of the inoculum (effectiveness of the pathogen in seed).

Low levels of seed-borne inoculum can lead to considerable disease incidence, so the most sensitive test should be used to determine the level of seed infection.

Where a high percentage of seed is infected, there is often more inoculum per seed associated with larger infections and deeper penetration.

It is recommended that diagnostic tests for viruses are conducted on germinated seed (seedlings), as disease may sometimes infect the seed testa without infecting the embryo or seedling.

Agriculture Victoria has prepared a summary, illustrated in Table 1, outlining common disease thresholds when considering using lupin seed for planting.

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As indicated, seed with less than 0.1 percent infection is recommended for sowing in high-risk areas and seed with less than 0.5 percent infection is best for sowing in low-risk areas.¹

Table 1: Seed health tests currently available and tolerance levels for seed infection in lupin²

Viruses	Laboratory A	Sample size submitted	Number of seeds tested	Seed infection threshold for acceptance of seedlot B	
				High-risk area	Low-risk area
AMV	1,2,5	3kg	1000	Less than 0.1%	Less than 0.5%
BYMV	2,5	3kg	1000	Less than 0.1%	Less than 0.5%
CMV	1,2,5	3kg	1000	Less than 0.1%	Less than 0.5%
PSbMV	2,5	3kg	1000	Less than 0.1%	Less than 0.5%
Bacteria					
<i>Pseudomonas syringae pv pisi</i>	2, 3	1kg	1000	Nil tolerance	Less than 0.1%
<i>Pseudomonas syringae pv syringae</i>	2,3	1kg	1000	Nil tolerance	Less than 0.1%
Fungi					
<i>Ascochyta and Botrytis</i>	1	1kg	400	Less than 1%	Less than 5%
<i>Ascochyta fabae</i>	2,4	1kg	400	Less than 1%	Less than 5%
<i>Ascochyta lentis</i>	2,4	1kg	400	Less than 1%	Less than 5%
<i>Ascochyta pisi</i>	2	1kg	400	Less than 1%	less than 5%
<i>Ascochyta rabiei</i>	2,4	1kg	1000	Nil tolerance	Nil tolerance
<i>Botrytis cinerea</i>	2,4	1kg	400	Less than 1%	Less than 5%
<i>Botrytis fabae</i>	2	1kg	400	Less than 1%	Less than 5%
<i>Colletotrichum lupini</i>	2	1kg	1000	Nil tolerance	Nil tolerance
<i>Mycosphaerella pinodes</i>	2	1kg	400	Less than 1%	Less than 5%
<i>Phoma pinodella</i>	4	1kg	400	Less than 1%	Less than 5%

^ASeed testing services: 1. AgriFood, 2. AGWEST, 3. AsureQuality, 4. SARDI, 5. TASAG. ^BThresholds given are a guide only. Growers should discuss the likely disease risk on their farm with local advisers. Wherever possible, only pathogen-free seed should be used. This is most important when a crop is being grown in a new area. It is important to note that a negative result from a seed test does not guarantee that a seed lot will be free from disease.³

(SOURCE: Agriculture Victoria)

1 Agriculture Victoria (2016) Seed health testing in pulse crops, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/seed-health-testing-in-pulse-crops>
 2 Agriculture Victoria (2016) Seed health testing in pulse crops, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/seed-health-testing-in-pulse-crops>
 3 Agriculture Victoria (2016) Seed health testing in pulse crops, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/seed-health-testing-in-pulse-crops>

2.2.2 Damage and germination tests

Being large, lupin seeds are prone to mechanical damage during harvest and when being handled after harvest (especially with augers). Weather and chemicals can also cause damage and all of these factors can reduce seed viability and germination.

Vigour and germination tests for lupin seeds are available to WA growers through accredited seed testing laboratories and can provide an indication of the proportion of seeds that will produce normal seedlings and help to determine seeding rates.

Typically, these tests require a 1 kg sample for every 25 tonnes of seed and are carried out over a 10-day period. Seed samples will be classified into normal seedlings, abnormal seedlings, dead seed, fresh seed and hard seed.

Fresh and hard seed results are mostly irrelevant in lupin germination tests. The focus should be on normal seedlings, which are fully viable, and abnormal seedlings, which show significant defects that will prevent the plant from growing into a typical productive plant even under ideal conditions.

Examples of abnormal seedlings include those with missing or damaged root systems, missing or damaged first leaves and missing or damaged growing points.

During the past 20 years, lupin germination test results from WA growers' seed have generally been in the 80 to 90 percent range. Samples with lower germination percentages than this should not be used for sowing.⁴

2.2.3 Nutrient tests

Seed of narrow leafed lupin produced in WA often has low Mn concentrations because of low Mn availability in the soil during grain filling.

Seed from WA crops may also have low P levels that produce small seedlings.

In the 1990s, The University of Western Australia (UWA) researchers studied whether low Mn levels in lupin seeds contributed to poor seedling establishment by reducing emergence.

In glasshouse trials, they showed a 40 percent increase in emergence using seeds with high Mn concentrations compared to using seed with low Mn concentrations.

All high Mn seed were viable, compared to low Mn seed that had 34 percent completely or partly non-viable.

The researchers concluded that low Mn supply during seed filling may lead to production of non-viable seed that cannot be visually distinguished from viable seed.⁵

Subsequent research has found germination and seedling growth in WA can be compromised when lupin seed Mn concentration is less than 13 milligrams per kilogram.⁶

Applying Mn fertiliser at sowing does not correct the effects of low concentrations of Mn in the seed.

Lupin crops without visible symptoms of Mn deficiency (also known as split seed syndrome) may still contain less than 13 mg/kg of Mn in the seed and, if in doubt, it should be tested (FeedTest offers WA growers lupin nutrient testing services for Mn, P and other nutrients on request).⁷

4 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

5 Crosbie, J, Longnecker, N, Robson, A (1994) Seed manganese affects the early growth of lupins in manganese-deficient conditions. The University of Western Australia, [http://research-repository.uwa.edu.au/en/publications/seed-manganese-affects-the-early-growth-of-lupins-in-manganesedeficient-conditions\(f5a7f18-bf1d-4921-b107-5fa309467a7d\).html](http://research-repository.uwa.edu.au/en/publications/seed-manganese-affects-the-early-growth-of-lupins-in-manganesedeficient-conditions(f5a7f18-bf1d-4921-b107-5fa309467a7d).html)

6 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

7 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

 MORE INFORMATION

GRDC 'Inoculating legumes: A practical guide': <https://grdc.com.au/Resources/Bookshop/2015/07/Inoculating-Legumes>

GRDC Grain Legume Handbook 'Inoculants': www.grdc.com.au/grainlegumehandbook

GRDC booklet 'Inoculating legumes: The Back Pocket Guide': <https://grdc.com.au/GRDC-BPG-InoculatingLegumes>

GRDC booklet 'Rhizobial Inoculants': <https://grdc.com.au/GRDC-FS-RhizobialInoculants>

DAFWA Bulletin 102008 'Producing Lupins': <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

Great Northern Rural Services YouTube video comparing inoculation and no inoculation in lupin crops: <https://www.youtube.com/watch?v=jT6jOpPuBno>

The easiest way to ensure the next year's lupin seed has sufficient Mn is to harvest from an area of the crop with the best soil type and that has been adequately fertilised with Mn.

The same applies for P, as using seed with P concentrations below 0.25 percent has been found to produce small seedlings that do not cope with stresses during early growth. Researchers have shown potential yield losses of 25 percent when seed with low concentrations of P is sown and, if in doubt, test seed to make sure it has at least 0.25 percent P.⁸

2.3 Inoculants

- Rhizobia inoculation can increase lupin yields and N fixation
- Gains are highest in low/no rhizobia soil
- Treat seed for paddocks sown to lupin for the first time
- Treat seed for neutral/alkaline soils every time a lupin crop is grown
- Treat seed for acidic soils every five years after a lupin crop
- Formulation options include peat, clay and peat granules, freeze-dried cultures and liquids
- Use a Group G or S inoculant.

Rhizobia are soil-dwelling root nodule bacteria that 'fix' atmospheric N in a form plants can use.

A fundamental characteristic of lupin (and other cultivated legumes) grown in Australia is the capacity to form a symbiotic relationship with these rhizobia.

This provides the total N requirements of the lupin plant, making it independent of the need for soil and fertiliser N, and injects N to the agricultural system for subsequent crops.

Some WA soils do not naturally contain rhizobia that form effective N-fixing symbioses with introduced lupin species and other legume crops, which has created a need to inoculate lupin seed with the appropriate rhizobia in some areas.

This inoculation increases lupin plant nodulation and biomass, grain production and yields, N fixation and post-crop soil nitrate levels to benefit subsequent crops.

All seed planted into paddocks that have not previously been sown to lupin requires inoculation.

On acidic soils (with a pH below 6.5 Calcium Chloride CaCl₂), after a well-nodulated lupin crop has been grown, a subsequent inoculation is not required for five years.

On neutral and alkaline soils (pH above 6.5), rhizobia do not survive for long and inoculation needs to be repeated every time a lupin crop is grown.⁹

Choice of inoculant group is critical for effective nodulation and N fixation to occur.

Lupin is nodulated by the slower-growing, acid-tolerant *Bradyrhizobium* from the commercial inoculant group G or S.

Lupin rhizobia G survive very well in low pH or sandy soils but, as the cost of inoculation is relatively low, it is advised that application can be worthwhile if there is any doubt about levels of residual soil rhizobia.

Commonly used inoculants for lupin in WA are moist peat and dry clay granules, which are cost effective and produce very good nodulation if handled and applied according to manufacturer instructions.

8 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

9 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

These products contain high numbers of living bacteria, which need to be maintained and protected from heat, excessive sunlight and cold to optimise effectiveness in the soil.

Table 2 outlines the suitability of a range of rhizobia inoculants available for lupin.

Table 2: Inoculation application methods and suitability <http://pulseaus.com.au/growing-pulses/publications/pulse-inoculation>¹⁰

Inoculant type	Applied to–	Suitable for dry sowing/ drying soil	Compatibility with seed applied fungicide	Time to sow after inoculation	Preparation or machinery requirements
Peat slurry	Seed	No	Some. Check the label	24 hours	Pre-sowing
	Seed furrow/ below seed	No	Yes	–	Liquid applicator on seeder
Freeze dried	Seed	No	No	Within hours	Pre-sowing
Granular inoculum	Seed furrow/ below seed	Yes	Yes	–	Mix with fertiliser
Liquid injection (peat or freeze)	Seed furrow	No	Yes	Within hours	Liquid applicator on seeder

(SOURCE: Pulse Australia)

Results from 2016 trials in south eastern Australia show liquid and granular rhizobia inoculants have some practical advantages in being easy to apply and separating rhizobia from potentially harmful seed-applied pesticides.

At two out of eight trial sites, inoculation significantly improved lupin crown nodulation from 0.05 to 13 nodules per plant. Nitrogen fixation increased by 175 kilograms of N per hectare at one site. For full results from these trials go to: <https://link.springer.com/article/10.1007/s11104-017-3317-7>¹¹

2.3.1 Peat inoculum

This is a reliable and cost effective method of applying rhizobia to the lupin seed and is typically carried out using a water or gum (usually methyl-cellulose) slurry.

Gum slurry provides the best results and protects the rhizobia when on the seed.

The packet size of peat inoculant is typically 2.5 kg and application rates are clearly outlined in the accompanying instructions. Rates are typically based on a target of achieving 100,000 rhizobia per lupin seed.¹²

The inoculant is mixed with water or gum to make the slurry and an adhesive solution can be added to improve contact between inoculant and seed.

Mixing is typically carried out with a concrete mixer; shovelling on a cement floor; or using a rotary coater/auger to get even coverage.

¹⁰ Pulse Australia (2016) Australian Pulse Bulletin, Pulse inoculation techniques, <http://pulseaus.com.au/growing-pulses/publications/pulse-inoculation>

¹¹ Denton, M, Phillips, L, Peoples, M, et al, Plant and Soil, July 2017, Legume inoculant application methods: effects on nodulation patterns, nitrogen fixation, crop growth and yield in narrow-leaf lupin and faba bean', <https://link.springer.com/article/10.1007/s11104-017-3317-7>

¹² White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

Label directions are important and caution is advised when adding insecticides, fungicides, herbicides, detergents or fertilisers – as these can be toxic to the rhizobia.

Rates of inoculum should be increased if seed has been treated with a fungicide and preferably sow this seed into moist soil within 24 hours (or as soon as possible).¹³

Bacteria in peat cultures is also vulnerable to damage from heat and direct sunlight, but will survive well if refrigerated at about 4 or 5°C until used (it is advised not to freeze this material).

Survival rates of rhizobia applied to seed using a slurry are higher when lupin is sown into wet soil than dry soil and it is recommended to double application rates when dry sowing.

In-furrow application of peat slurry (or liquid inoculants) directly into the seed row is gaining in popularity, as this is well adapted to both modern machinery and pulse growing.

This method is suitable when machines are set up for liquid N application on cereals, or where fungicides are used to treat seeds prior to sowing. It requires at least 80 litres or more of water per hectare.

The solution is sprayed into the soil, has the convenience of being dissolvable and does not require filtering – but caution is required before mixing with any fungicides.

It is also advisable not to sow trace element fertilisers containing copper (Cu) with slurry-inoculated lupin seed, as Cu is toxic to rhizobia.

Dry dusting peat inoculum on to lupin seed is not effective for WA conditions.

2.3.2 Clay granules

Granule inoculants are comprised of prilled peat, clay or a mixture of both and come in a range of forms that are dry or moist, uniform or variable, powdery, coarse or fine.

These are applied similarly to a fertiliser – as a solid, in the seed furrow or near to seed – and can be more flexible and practical than using peat slurry.

Clay granule products tend to contain fewer rhizobia than peat-based inoculants and typically need to be applied at higher application rates, in a range from 5 kg/ha to 10 kg/ha when sowing on 18 cm row spacings.¹⁴

These can be mixed with fertiliser when it is drilled with the seed (not banded).

When sowing lupin crops into dry soil, dry clay granules are best used compared to peat-based products.

2.3.3 Inoculants and fungicide seed treatments

Research has shown fungicide seed dressings for lupin (including iprodione, procymidone and thiram) do not interfere with the rhizobia population in soil from previous lupin crops, but are toxic to rhizobia applied to the seed in inoculants.¹⁵

If inoculating seed that has been dressed with fungicide using a peat-based product it is best to:

- » Allow fungicide to dry before inoculating seed
- » Apply inoculum at double the standard rate
- » Apply inoculum immediately before sowing
- » Sow seed into moist soil
- » Alternatively, use a dry clay granule inoculant.

¹³ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

¹⁴ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

¹⁵ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

i MORE INFORMATION

DPIRD-GRDC MyCrop website
 'Monitoring pulse nodulation': <https://www.agric.wa.gov.au/mycrop/monitoring-pulse-nodulation>

GRDC 'Inoculating legumes':
<https://grdc.com.au/GRDC-Booklet-InoculatingLegumes>; www.grdc.com.au/GRDC-BPG-InoculatingLegumes

2.4 Calculating nodulation after inoculation

Nodulation of lupin roots is important to maximise N fixation and plant growth.

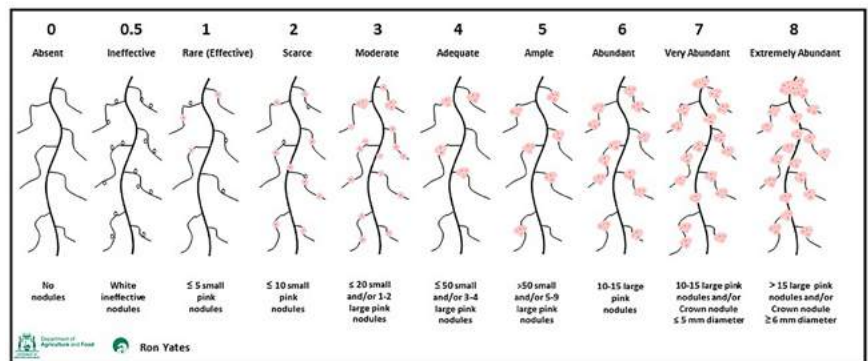
Healthy nodules need to be present on the taproot and lateral roots.

A healthy N fixing nodule is pink inside. Grey or green nodules do not fix N.

Nodulation of the lupin plant after treating with an inoculant can be assessed 10 to 12 weeks after sowing and typically the best time to check roots is late winter and early spring.

Abundant levels of nodules will appear pink as indicated in Figure 1.

Figure 1: Degree of nodulation found on pulse plants.¹⁶



(SOURCE: DAFWA)

Guidelines for assessing lupin nodulation include:

- Carefully dig 10 plants at random across the area to be assessed
- A minimum of three sites should be sampled
- Best areas are 20 m, 60 m and 100 m in from crop edges
- Keep the soil intact around the root ball
- Wash dirt off roots in a bucket of water
- Soak roots from heavy soil if necessary
- Observe the size, number and colour of the nodules on the root system
- Score the root system for each sample for the percentage of plants adequately nodulated – as shown in Figure 1.
- Calculate an average score for the three (or more) sites sampled.¹⁷

It is advisable to look for the number of nodules on a plant and where these are located.

There should be more nodules around the crown of the plant (where root meets shoot) if an inoculant was used and these will boost early seedling growth.

Lupin crops that were not inoculated tend to have nodules spread across the root system on crown, taproots and laterals if rhizobia is present in the soil.

Poor nodulation may be due to agronomic factors that could include:

- » Poor environmental conditions (cold temperatures, moisture stress) during emergence and crop growth
- » Soil pH (may not suit survival of the particular rhizobia for the crop)
- » Poor establishment of soil rhizobia by previous crops grown in the paddock
- » Poor inoculation
- » Fertiliser practices
- » Root diseases, such as rhizoctonia.¹⁸

¹⁶ DPIRD-GRDC MyCrop (2016) Monitoring pulse nodulation, www.agric.wa.gov.au/mycrop/monitoring-pulse-nodulation

¹⁷ DPIRD-GRDC MyCrop (2016) Monitoring pulse nodulation, www.agric.wa.gov.au/mycrop/monitoring-pulse-nodulation

¹⁸ DPIRD-GRDC MyCrop (2016) Monitoring pulse nodulation, www.agric.wa.gov.au/mycrop/monitoring-pulse-nodulation

2.5 Time of sowing

- Early sowing optimises yields and profits
- Early sowing is more important in low rainfall areas
- Delayed sowing can assist weed control in some high rainfall areas and helps avoid poor pod set from excessive plant height, lodging and biomass production
- Variety choice will impact on time of sowing.

Early sowing is a key to successful lupin crop establishment and profitability in WA, along with good weed control, achieving optimum plant density, incorporating pre-planting residual herbicides, seed depth placement and adequate fertiliser.

Sowing lupin crops early allows seed to germinate in warmer temperatures, promoting early root growth and nodulation.

But there is a balance and sowing too early can result in issues with excessive growth, lodging and poor pod set in some years and environments.

Early sowing is more critical in WA's low rainfall zones because potential yield is lower. Research has shown the highest rates of yield loss caused by delayed sowing in these areas start to occur early in the season.

In high rainfall zones, the highest rates of yield loss caused by delayed sowing do not start until the second half of May and this can be an advantage for weed control in these areas.

Lupin will typically perform best when sown into a moist seedbed to ensure good and even establishment, nodulation and activation of soil herbicides such as simazine.

But lupin crops are increasingly sown dry in WA, mainly to fit in with timing of cereal sowing programs.

Tables 3-5 show the pros and cons of dry, moist and delayed sowing for lupin crops in WA.

Table 3: Advantages and disadvantages of dry sowing lupin¹⁹

Dry Sowing	
Positives	Negatives
Crop is given longest growing season possible	Simazine incorporation is uneven when applied in dry soil. Simazine activity can be poor and weed burdens high
Enables rapid establishment in warm soil	Germination on marginal moisture can lead to poor and uneven crop establishment
Logistically simple	Weeds grown through ineffective control are difficult and expensive to control
Brings forward time of sowing for other crops	Paddocks prone to wind erosion if ground cover is sparse
Improves machinery efficiency	Paddocks with WA blue lupin require a knockdown prior to sowing, as there is no selective herbicide for blue lupin control

(SOURCE: DAFWA)

In situations where growers decide to dry sow, it is recommended to consider sowing into paddocks with good stubble cover to avoid erosion. Sowing into paddocks with low weed burdens can assist with poor simazine incorporation and increasing seeding rate can assist in counteracting poor establishment.²⁰

¹⁹ DPIRD (2016) Lupin essentials – growing a successful lupin crop, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C1#smartpaging_toc_pf_s0_h2

²⁰ DPIRD (2016) Lupin essentials – growing a successful lupin crop, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C1#smartpaging_toc_pf_s0_h2

Table 4: Advantages and disadvantages of moist sowing lupin²¹

Wet sowing (on the break of 15 millimetres over two days)	
Positives	Negatives
Higher potential for even, competitive lupin crop emerging	Rapidly drying soil after the break can reduce crop establishment success
Simazine applied prior to break will wash into soil, giving maximum weed control	Sowing naturally dries soil, reducing remaining soil moisture for germination and establishment
Trifluralin effectiveness is increased when applied into moist soil on first rain	
Even crops assist effective post-emergent herbicide use	
Opportunity to achieve a knockdown of weeds, including WA blue lupin	

(SOURCE: DAFWA)

Wet sowing success will hinge on effective use of pre-seeding herbicides to ensure weeds that germinate with the crop remain under control.²²

Table 5: Advantages and disadvantages of delayed sowing after the break of lupin into wet soil²³

Delayed sowing (after the break)	
Positives	Negatives
Allows the full benefit of knockdown herbicides to take affect	Risk of long gap between break and follow up rains can affect crop success
	Rate of yield loss from delayed sowing is greater in low rainfall zones
No simazine application prior to season break allows greater sowing flexibility	Slower germination and establishment due to cooler soil temperatures
Wet soil guarantees even competitive crop emergence	Potential delay to cereal program
Well suited to earlier maturing new varieties such as PBA Leeman [Ⓛ] , PBA Jurien [Ⓛ] , PBA Gunyidi [Ⓛ] and PBA Barlock [Ⓛ]	

(SOURCE: DAFWA)

i MORE INFORMATION

DAFWA 'Producing Lupins' Bulletin:
<http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

2.6 Geographic location

Optimum sowing dates for WA lupin crops can be loosely calculated on rainfall areas. Northern region crops are typically best sown from the end of April and before the first week of June and southern region crops are best sown from early May.

Typically, lupin will perform best in areas with an annual average rainfall of less than 350 mm when sown from mid-April to early May.

Areas with an annual average rainfall of 350 mm to 450 mm suit a mid-April to early May sowing date (although loam soils in both of these zones require later sowing).

Higher rainfall zones with average annual rainfall of 450 mm and above suit sowing of lupin from mid to late May.

21 DPIRD (2016) Lupin essentials – growing a successful lupin crop, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C1#smartpaging_toc_p1_s0_h2
 22 DPIRD (2016) Lupin essentials – growing a successful lupin crop, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C1#smartpaging_toc_p1_s0_h2
 23 DPIRD (2016) Lupin essentials – growing a successful lupin crop, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C1#smartpaging_toc_p1_s0_h2

If sowing is too late in any of these areas, potential yield losses can be significant for every week's delay.²⁴

Research in the central grainbelt in 2006 found that by delaying sowing by three to four days, lupin yield loss was similar to the yield loss caused by one wild radish plant/m² growing in the crop.²⁵

Optimum flowering time for lupin varies little throughout the State and, typically, should start in early August.

Very early sown crops can be more exposed to damage from frost or heat/drought stress during flowering and early podding in conducive seasons.

In areas with long growing seasons, such as the South Coast, sowing too early can result in excessive vegetative growth and lodging in some years.

2.7 Varieties

Narrow leafed varieties PBA Leeman[®], PBA Jurien[®], PBA Barlock[®], PBA Gunyidi[®], Mandelup[®] and Coromup[®] – and the albus lupin Amira[®] – are early maturing and provide opportunities to delay sowing into late May.

This can improve pre-planting weed and disease control without compromising yield.

These newer lupin varieties for WA carry a high proportion of yield on the main stem relative to other varieties.

This allows them to be high-yielding without relying heavily on late maturing lateral branches. This further reduces the need for early sowing, compared with older lines, such as Tanjil[®] and Wonga, that rely more on the lateral branches for yield.

The newer narrow leafed and albus varieties tend to perform better in WA's high and medium rainfall areas, where season length is long and early sowing is not as critical to ensure that seed in lateral pods will fill.

But the interaction of sowing time with variety is usually much lower than the interactions between sowing time and location.

(More information about lupin varieties is outlined in Chapter 3).

2.8 Tillage systems

Machinery used to sow lupin crops should ideally be able to:

- Handle thick stubble
- Uniformly incorporate simazine into the top 5 cm of soil
- Kill germinated weeds
- Place seed and fertiliser uniformly at desired depth/s
- Leave a good seedbed with water-harvesting furrows
- Leave loose soil above the seed
- Sow quickly and cheaply.²⁶

Most WA lupin crops are sown with tyned machines, often with press wheels.

This provides good seed-to-soil contact and forms a furrow that harvests water, which is particularly important in achieving a uniform establishment of lupin crops in non-wetting sands and protecting seedlings from sandblasting.

Knife point machines provide good stubble handling and reasonable incorporation of herbicides, depending on row spacing.

MORE INFORMATION

Online Farm Trials report 'The effects of sowing time and radish density on lupin yield': <http://www.farmtrials.com.au/trial/10449>

²⁴ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

²⁵ Harries, M (2006) Interaction of time of sowing and weed management of lupins, DAFWA, <http://www.farmtrials.com.au/trial/10420>

²⁶ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

These systems kill germinating weeds in the seeded row, allow flexibility for placing seed and fertiliser and are relatively fast and easy to use.

The weight of the press wheel should be set no higher than 2 kg/cm width of the press wheel.

Where deep furrows are created, there is a danger that soil-applied herbicides, such as simazine, will wash into these and concentrate at toxic levels.

This can be avoided in knife point systems by applying herbicide prior to sowing, but it is important to control herbicide throw.

Disc machines are ideal for stubble retention, but triple discs are less efficient at herbicide incorporation and pre-planting weed control than tined or culti-trash machines.

Disease spores tend to be found near the soil surface and will remain there with minimal soil disturbance. Seed placed below the spore layer at a depth of 2–3 cm will have a much lower exposure to infection.²⁷

Management of rhizoctonia bare patch, an issue that cannot be controlled by rotating crops, is complex in crops established using zero or minimum tillage. The chances of this occurring can be reduced by sowing at a depth of 3–5 cm and cultivating 5–10 cm below this in a direct drilling operation.

2.9 Seeding rates and plant density

Narrow leaved lupin tends to respond best to seeding rates of 80-120 kg/ha (of 75 percent germinable seed), depending on seed size and germinability, to meet a target plant density of 45 to 70 plants/m².²⁸

But trials across WA have found optimum plant densities will change depending on location and season.

There is typically little or no yield penalty if plant densities are higher than the recommended range of up to 70 plants/m², but yield losses in newer varieties can be substantial if lupin plant populations fall below 40 plants/m².²⁹ This is because these varieties rely on pod set on the main stem, rather than on branches.

A high-density crop may produce fewer pods per plant, but have more pods/m² and a higher yield than a low-density crop.

Aside from yield, a high plant density crop also has benefits of:

- » Less weed growth
- » Better crop competition with weeds
- » Less risk of Brown leaf spot and CMV incidence/severity
- » Better compensation from root disease losses
- » More compensation if there is poor establishment (especially on water repellent sands)
- » Lower susceptibility to wind erosion and sandblasting
- » Greater ease of harvesting.

Table 6 outlines thresholds for narrow leaved lupin sowing rates (kg/ha) required to achieve 45 plants/m², assuming a 90 percent establishment rate.

27 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

28 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

29 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

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Table 6: Thresholds for narrow leafed lupin sowing rates (kilograms per hectare) to achieve a plant density of 45 plants per square metre³⁰

Germination rate %	Lupin Seed Weights g/1000seeds		
	140g	160g	180g
70	100	114	129
80	88	100	113
90	78	89	

(SOURCE: DAFWA)

Albus lupin does not tend to require quite as high a plant density as narrow leafed lupin.

Taking into account a larger seed, the suggested sowing rate is about 160 kg/ha to achieve a density of 45 plants/m² (based on limited trial data).³¹

The following formula can be used to calculate lupin sowing rates for albus and narrow leafed varieties:

$$\text{Sowing rate (kg/ha)} = \frac{\text{Seed size (g/1000 seeds)} \times \text{Target density (plants/m}^2\text{)} \times 100}{\text{Germination rate (\%)} \times \text{Establishment rate (\%)}}$$

(SOURCE: DAFWA)³²

Table 7 shows the sowing rates needed to achieve the ideal plant density of 45 plants/m² for seed with a range of germination rates, determined by commercial seed tests.

Table 7: Sowing rate (kg/ha) required to achieve 45 plants/m² (target plant density for seed with different germination rates %

Germination Rate (%)	Sowing rate (kg/ha) using various seed weights (140-180g g/1,000 seeds)				
	Small	Medium	Large		
	140	150	160	170	180
70	100	107	114	121	129
75	93	100	107	113	120
80	88	94	100	106	113
85	82	88	94	100	106
90	78	83	89	94	100
95	74	79	84	89	95
100	70	75	80	85	90

Note: Sowing rates assume wet sowing where establishment rate is 90 percent. For dry sowing where establishment rate is 85 percent, add a further 5 percent to the sowing rate.

(SOURCE: DAFWA Producing Lupins Bulletin)³³

30 DPIRD (2016) Lupin essentials – growing a successful lupin crop, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C2#smartpaging_toc_p2_s1_h2

31 DPIRD (2016) Lupin essentials – growing a successful lupin crop, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C2#smartpaging_toc_p2_s1_h2

32 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

33 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

2.10 Sowing depth

Ideally, the sowing depth for lupin across the WA grainbelt is 3-5 cm, but this varies marginally depending on soil type.

Shallow sowing at a depth of 2-3 cm can be used on harder setting heavier soils. This can reduce rhizoctonia hypocotyl rot because the stem or hypocotyl of the seedling has less soil to grow through and less chance coming in contact with the fungus.

Sowing to a depth of 5 cm will reduce occurrence of pleiochaeta root rot, as seed is placed below most of the spores that have fallen to the ground from previous brown leaf spot infections.

It is recommended to not sow lupin seed deeper than 7 cm in most areas of WA, as crop establishment can be very uneven and poor.³⁴

³⁴ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

i MORE INFORMATION

DAFWA Bulletin 102008 'Producing Lupins': <http://researchlibrary.agric.wa.gov.au/cqi/viewcontent.cqi?article=1009&context=bulletins>

DPIRD website hub 'Lupins – germination and seedling development': <https://www.agric.wa.gov.au/lupins/germination-and-seedling-development-lupins>

Plant growth (phenology) and development

3.1 Overview

Lupin plant growth and development are overlapping and complex.

Growth refers to the increase in size and number of leaves, stems and roots – which produce biomass. Fuelled by SOURCEsynthesis, this is directly related to water use and light interception.

Development is the process by which the plant moves from one growth stage to the next. Rate and timing depend on variety, SOURCEperiod and temperature.

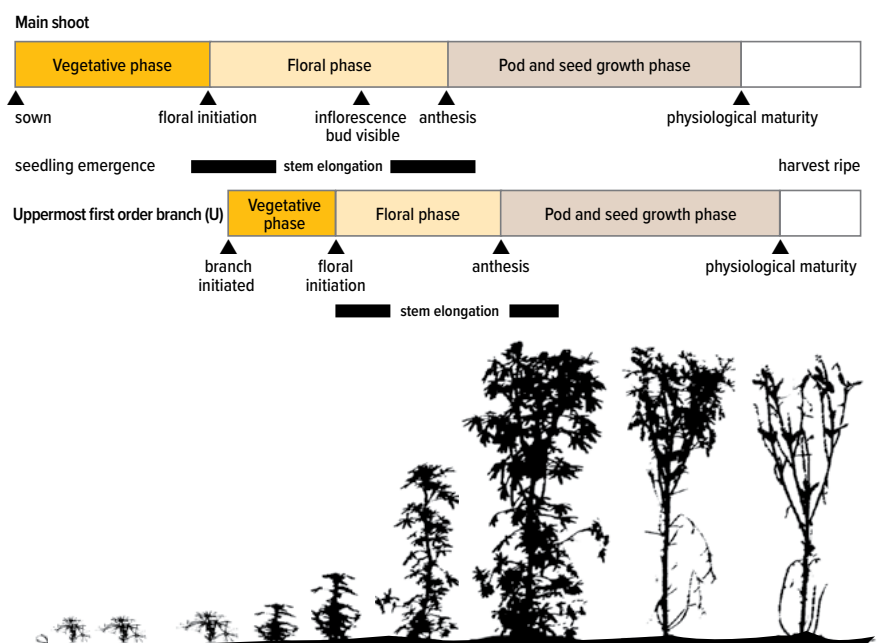
Correct identification of lupin plant growth stage enables effective crop management, especially for herbicide and pesticide applications and timing of harvest.

A growth scale is used to describe each developmental stage of the lupin plant and this is similar to the Zadoks Growth Scale for wheat.

The lupin growth scale covers six stages, starting with germination and finishing with seed ripening, and is sub-divided into 10 units per stage.

Some of the growth stages overlap during the plant's evolution, as can be seen in Figure 1.

Figure 1: Life cycle of lupin plant.



(SOURCE: DAFWA)¹

¹ Walker, J, Hertel, K, Parker, P, Edwards, J (2010) Lupin Growth and Development, Industry and Investment NSW, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/516183/Proccrop-lupin-growth-and-development.pdf

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But the stages are recognised as separate in plant development, as outlined in Table 1.²

Table 1: Lupin growth stages and numeral system

STAGE	DECIMAL SCORE
GERMINATION AND SEEDLING 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 seed coat	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 emerged 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
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

² Walker, J, Hertel, K, Parker, P, Edwards, J (2010) Lupin Growth and Development, Industry and Investment NSW, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

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STAGE	DECIMAL SCORE
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: DAFWA)³

The plant is formed by leaves, flower spikes, branches, stem, roots, pods and seeds. Historically, lupin categories have fitted into early, mid and late flowering varieties.

But early flowering varieties now make up the bulk of plantings in Western Australia and have no vernalisation (cold period) requirement before flowering.

If sown before mid-April, these varieties can start flowering in the cold and frosty conditions experienced during the winter growing period across southern Australia. Mid and late flowering varieties will often flower after typical cold and frosty periods. In some warmer, more northern, environments, late types may flower during periods of heat stress, which can affect yield.

Older narrow leafed lupin varieties, such as Wonga, will branch and flower as long as the season permits. These produce most grain yield in the primary and first lateral pod set stages.

Newer, restricted branching types, such as PBA Leeman^ϕ, PBA Jurien^ϕ, PBA Barlock^ϕ, Mandelup^ϕ and Gunyidi^ϕ, are limited in branching habits.

These lines can typically compensate for poor early pod set, as a lower proportion of grain yield potential comes from the primary and first lateral flowers.

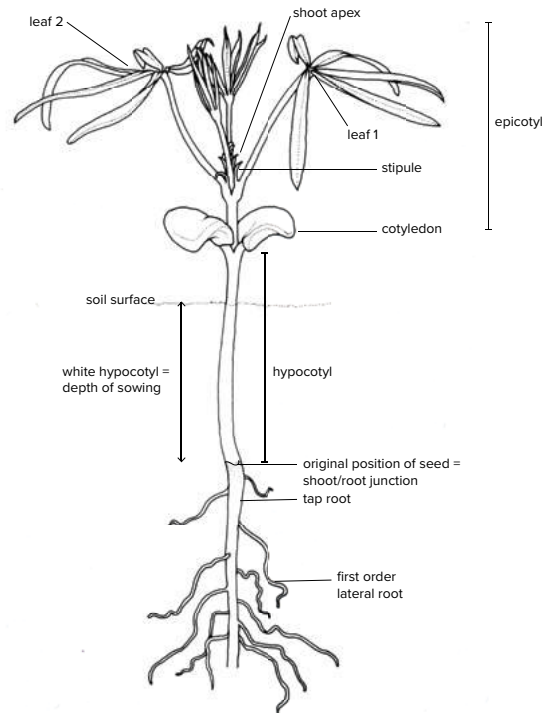
Australian lupin breeding advances have led to the development of varieties with less branching and more pods on the primary stem.

This has been in response to key productivity limitations of excessive and indeterminate vegetative growth and branching habits of traditional varieties, especially in narrow leafed lupin.

³ Walker, J, Hertel, K, Parker, P, Edwards, J (2010) Lupin Growth and Development, Industry and Investment NSW, http://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

3.2 Germination and seedling emergence

Figure 2: Diagram of narrow leaved lupin seedling to indicate the positions of various parts



(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

Germination includes the three phases of water absorption, activation and visible germination and can take from five to 15 days.

The length of the phase depends on soil temperature, moisture and sowing depth, but is typically not determined by variety.

This growth stage starts when seed water content reaches about 60 percent of the seed weight.

The seed has the ability to grow in very dry soils and will not stop growing during moisture stress.

The swollen seed produces hormones and this engages enzymes and metabolism activity needed for starch to be broken into sugars for growth.

It is after this occurs that the radicle (growing plant embryo) ruptures the seedcoat (testa) of the seed and forms the anchor in the soil.

The roots form as a taproot system and then lateral roots grow out to form the secondary root system.

The root system size and pattern change between species and the nodules containing the important rhizobia bacteria to fix nitrogen (N) in the soil form on this root system.

The hypocotyl, which is the long and white stem, simultaneously grows towards the surface.

3.3 Leaf emergence



Figure 3: *Lupin at early stages of development.*

(SOURCES: GRDC)

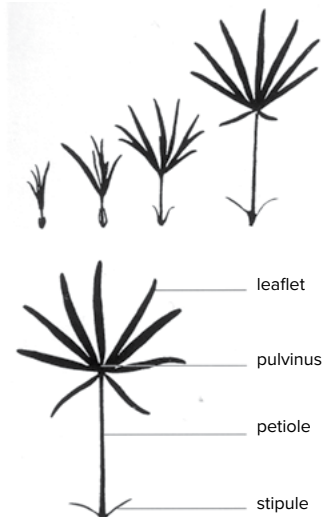
This is known as the epical seedling stage and is where cotyledons form and expand above the ground. The first leaf will grow from the centre of the cotyledons, while at the same time, root formation continues.

The leaves are formed as a palmate structure, with leaflets coming from a central point.

Narrow leafed lupin has narrow, pointed leaves, which increase in number towards the top of the plant.

As shown in Figure 4, initially, there are five leaflets per leaf and – towards the top of the plant – there can typically be between nine and 12.

Figure 4: *Stages of lupin leaf emergence.*



(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

The plant is heliotropic, turning out in the day for sunlight interception and moving back to face the rising sun. This process occurs until flowering begins.

A crop is said to be established when 50 percent of seeds have germinated, emerged and are developing with strong seedling vigour.

Germination, emergence and establishment of the seed can be affected by several factors, including moisture, temperature, soil crusting and seed quality.

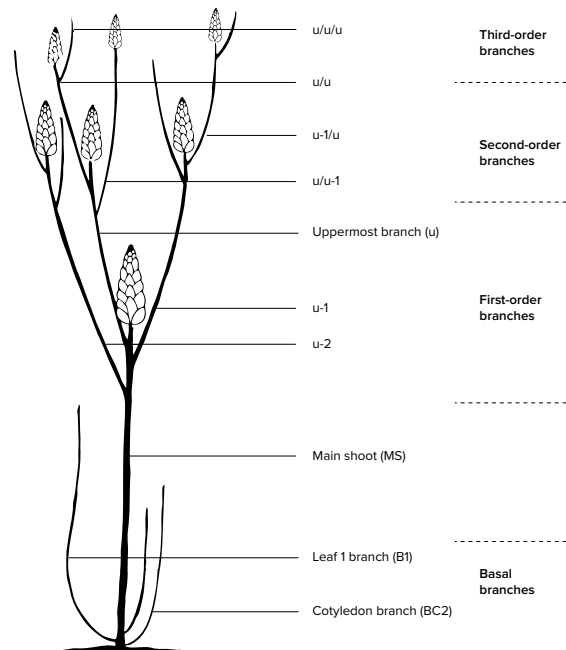
3.4 Stem elongation and branching



Figure 5: The lupin plant has a branching habit and each branch has its own flower spike.

(SOURCE: GRDC)

Figure 6: Branching in lupin plants occurs in stages illustrated in this diagram



(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

This phase occurs during the vegetative and reproductive phases of growth.

If the plant has access to adequate moisture, nutrients and sunlight, the branches and stem grow new lateral branches with flower spikes through to the reproductive phase.

The stem develops first and then each branch has its own flower spike, on which pods tend to mature at the same time.

Stem elongation is affected by accumulated temperature. This means that in the vegetative phases in winter, stem growth can be slow.

Stem growth occurs as the internodes of the stem develop. This development can be at a rate of 0.1–0.2 millimetres per growing degree day (GDD), which is a measure of heat accumulation used to predict plant and pest development rates.

The main stem reaches its maximum length at about 1050 GDD.

Each variety will vary, with early flowering varieties having fewer nodes than later flowering varieties.

Nodules containing the N fixing bacteria (*Bradyrhizobium lupini*) are mainly formed on the top 5–10 cm of the taproot and first appear three to four weeks after germination.

3.5 Flowering



Figure 7: Crop of flowering narrow leaf lupin with white flower heads standing above a lush green crop.

(SOURCE: Cox Inall Communications)

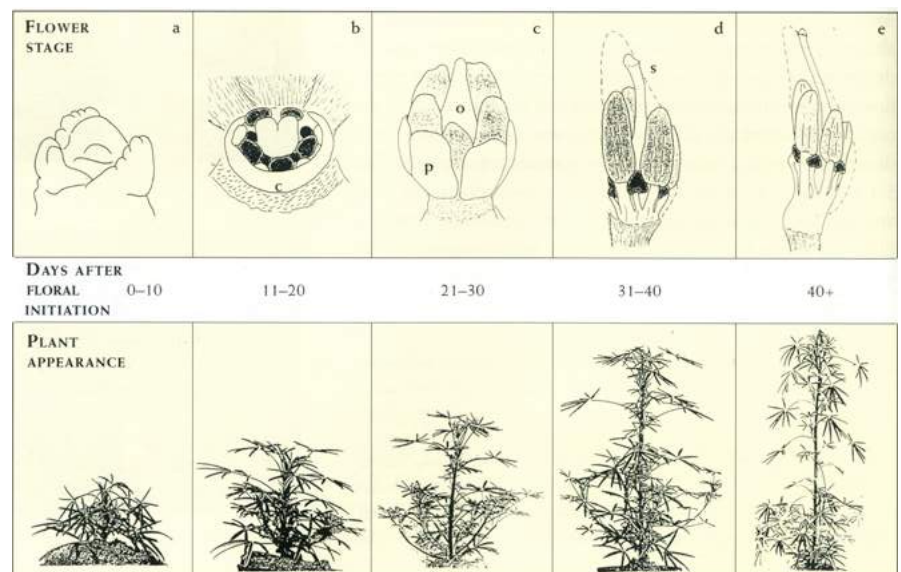


Figure 8: Flower development of lupin plants.

(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

Typically, flowers form on the upper branches and these produce most of the lupin grain yield.

The flowering forms part of the reproductive development stage of the plant, which starts after the main stem stops forming leaves. Flowers begin to grow over several days to form a flower spike (raceme).

The flower spike forms at the end of each branch and consists of several individual flowers.

The flowers have five petals and will flower for about 10–14 days. The whole plant tends to have flowers for a period of four to eight weeks.

Flowering occurs along the whole length of the flower spike, from the base to the end of the stem.

The pollination and fertilisation stages of the flower must occur for pod ripening to start.

Narrow leafed lupin is self-pollinating and little cross-pollination can occur via insects. Varieties remain pure through this mechanism and insects do not increase pod development or yield.

The albus lupin has a similar pollination process, but cross-pollination can occur more readily.

Branch growth is very sensitive to moisture and temperature stress, so earlier sowing and flowering typically enables the production of more branches.

Varieties such as PBA Leeman[®], PBA Jurien[®], PBA Barlock[®] and Mandelup[®] carry a high proportion of yield on the main stem relative to other varieties, which is an additional advantage.

These varieties can produce high yields without relying heavily on late maturing lateral branches, which also reduces the need for very early sowing.

Older varieties, such as Wonga, rely more on the lateral branches for yield. This variety performs better at high and medium rainfall locations where the season length is long and early sowing is not as critical to ensure that seed in lateral pods will fill.

3.6 Pod ripening



Figure 9: *Lupin pod walls harden close to the stem and keep the pod attached to the flower spike.*

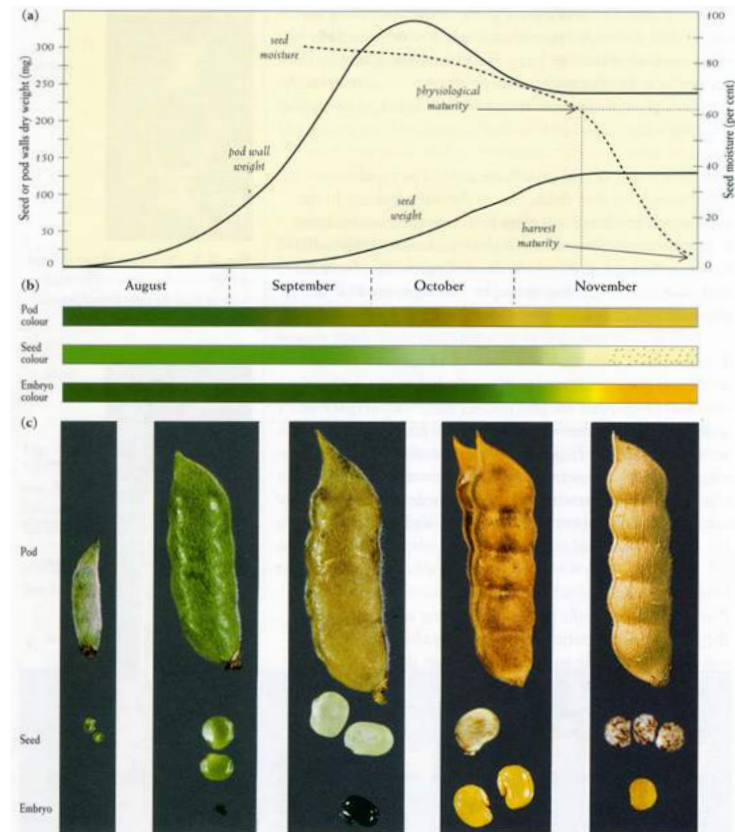
(SOURCE: GRDC)

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Figure 10: Pod and seed development, note the dates are typical for conditions in WA.



(SOURCE: Dracup, M. Kirby, E.J.M (1996) University of Western Australia, Lupin: Development Guide, trove.nla.gov.au/work/21902398)

Pod formation occurs as a result of a fertilised flower ovary. Not all fertilised flowers will set pods and these can be identified by a stalk changing from green to yellow before being shed.

Newer lupin varieties are bred to have higher levels of pods than older varieties, but it is common for a high number of flowers to be shed as a result of environmental factors, such as moisture stress and high temperatures.

If a fertilised flower ovary is to create a pod, the pod wall will harden close to the stem and keep it attached to the flower spike.

A pod that reaches 8–10 millimetres in length is considered to be set and, typically, is unlikely to fail. Pod walls continue to thicken before seeds develop and then provide nutrients for developing seeds.

During the early stages of pod development there is strong competition with vegetative growth elsewhere in the plant and this influences successful pod set.

Colour changes of the pod (from green, through to khaki and to light brown) and the developing cotyledons in the seed (from green to yellow) are useful indicators of the physiological stage of maturation of the lupin plant.

Breeding advances in lupin have addressed previous problems with pod shattering during this phase of plant growth and harvest. PBA Leeman[®], PBA Jurien[®], PBA Barlock[®] and PBA Gunyidi[®] are some of the varieties benefitting from improvements in this trait, having resistance to pod shatter.

3.7 Seed ripening

Seeds expand as they develop, taking on protein, carbohydrates and nutrients when the pods have reached full length and thickness.

Most pods develop five or six seeds over a period of 38 to 72 days.

Seed maturity is reached when the seeds complete collection of nutrients from the pod, there is no functioning connection to the plant and the maximum dry weight is achieved.

Leaves on the main stem and lateral branches die off. From here, the seed, which can have a 62 percent moisture content reading at this stage, will continue to dry out to 13–14 percent moisture.

Total plant maturity is reached when more than 90 percent of the pods on the highest branches have reached maturity.

3.8 Lupin breeding advances

Australia is recognised as a world leader in lupin production due to a coordinated breeding and agronomic research effort, linked to an innovative farming community.

Weed management, herbicide tolerance, anthracnose resistance and yield reliability are the biggest agronomic issues being addressed by national lupin breeders to continue improving the productivity of this crop.

The Department of Primary Industries and Regional Development (DPIRD) – formerly The Department of Agriculture and Food Western Australia (DAFWA) – was the breeding centre for lupin crop development for 45 years and consistently released varieties for higher production and crop legume rotation benefits.

Initially, breeding efforts focused on early flowering and resistance to grey leaf spot, which threatened the industry in the 1970s. In more recent years, breeders have been working on improving adaptation, yield potential and resistance to other diseases.⁴

This led to the development and release of varieties with resistance to phomopsis, which causes lupinosis in grazing animals, in 1988 and anthracnose in 1996.

DPIRD then increased its emphasis on breeding for better herbicide tolerance and grain quality.

At the same time, there was development of narrow leafed varieties with less (or restricted) branching to reduce excessive plant growth and boost pod set and pod seed-fill.

Restricting branching curbs the competing demands of vegetative and reproductive growth in the plant, which often occurs when growing conditions are deteriorating in southern Australia.

Researchers in the late 1990s started selecting for restricted branching in narrow leafed lupin and this led to germplasm being included in national breeding programs for the development of current varieties with these traits.⁵

The Grains Research and Development Corporation (GRDC) and DPIRD announced in 2016 that Australian Grain Technologies (AGT) would take forward Australia's lupin breeding program.

AGT advises it will be examining how to best increase the value of lupin in Australian farming systems through improved yield, disease resistance, broader adaptation, herbicide tolerance and seed quality.⁶

4 White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cqi/viewcontent.cqi?article=1009&context=bulletins>

5 Dracup, M, Thompson, B (2000) Narrow Leafed Lupins with Restricted Branching. DAFWA, CLIMA, <http://aob.oxfordjournals.org/content/85/1/29.full.pdf+html>

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

MORE INFORMATION

GRDC 'More Profit from Crop Nutrition': <https://grdc.com.au/Research-and-Development/Major-Initiatives/More-Profit-from-Crop-Nutrition>

GRDC Fact Sheet 'Better fertiliser decisions for crop nutrition — Western': www.grdc.com.au/GRDC-FS-BFDCN

GRDC Fact Sheet 'Soil testing for crop nutrition — Western': <https://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-West>

GRDC Hot Topic: 'Micronutrients in the western region': <https://grdc.com.au/Media-Centre/Hot-Topics/Micronutrients-in-the-western-region>

Better Fertiliser Decisions for Cropping Systems in Australia: www.bfdc.com.au

Australian Soil Classification: <http://www.clw.csiro.au/aclep/asc/>

DPIRD MySoil: <https://www.agric.wa.gov.au/mysoil>

SoilMapp: www.csiro.au/soilmapp

Nutrition, fertiliser and benefits in the rotation

4.1 Overview

- Use soil/plant tissue tests or paddock history to determine fertiliser use and rates
- Deep soil testing – to 30 centimetres – is valuable
- Drill phosphate at seeding but beware of toxicity to seed or inoculum if either high rates are drilled or if the seeding row is narrow
- On some soils, banding phosphate below the seed can increase yields
- If needed, apply potassium (K) within four weeks of sowing
- On potentially manganese (Mn)-deficient soils (mainly light sands) use Mn super, deep banded or as a spray when first pods are 2.5 cm
- Monitor trace elements/micronutrients (especially if not applied within past 15 years).¹

Western Australia's infertile sandy soils are ideal for production of lupin.

Roots of narrow leafed and albus varieties have many long hairs and some (mostly albus lines) produce specialised cluster roots and/or secrete organic acids (mostly narrow leafed lines) that help to solubilise soil nutrients.

Being relatively large, lupin seeds can store nutrients to sustain early growth of crop seedlings in infertile soils.

If rhizobia are present (through current or past seed inoculation), nitrogen (N) fixing occurs.

Lupin plants tend to have a low utilisation of soil inorganic N.²

Fixed N becomes available to the lupin plant about five to six weeks after sowing.

Application of other key nutrients – as fertilisers – can be required for WA lupin crops to maximise profitability.

Phosphorus (P), molybdenum (Mo) and Mn are the nutrients most likely to be deficient in WA soils that can produce a crop response when added to the lupin phase of the rotation in some years, along with the trace elements/micronutrients copper (Cu) and zinc (Zn).³

Other important nutrients to monitor in lupin crops in this State include N, K and sulfur (S) – along with some trace elements.

But these are rarely deficient for lupin crops because either rhizobia are present in the soil (for N) – or K and S fertilisers have been applied to other crops (typically wheat or canola) in the rotation and residual levels are usually sufficient for lupin crops. Sulfur deficiency tends to occur when fertilisers containing low levels of S have been used, or in years where there is high rainfall in June and July.⁴

¹ DPIRD (2016) Lupin essentials – growing a successful lupin crop, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-a-successful-lupin-crop?page=0%2C2#smartpaging_toc_p2_s4_h2

² Unkovich et al (1997); Anderson et al (1998) Nitrogen (N) field study of lupin below-ground N cycling. The University of Western Australia, http://research-repository.uwa.edu.au/files/1530547/11189_PID11189.pdf

³ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

⁴ White, P, French, B, McLarty, A (2008) Producing Lupins. Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

Lupin typically has a lower S requirement than wheat, which – in turn – has a lower S requirement than canola.

The low S fertiliser requirement in WA lupin crops appears to be related to the plant using subsurface S, or from having S demand late in the growing season when the root system is well developed.

Soil S critical values for lupin crops are likely to be less than those for wheat crops, but there are insufficient studies on soils with low soil S status to define a soil critical value for S.

Soil tests for Mn are poor and tissue testing the main plant stems is recommended.

Plant tissue testing is a valuable management tool that can help determine any crop nutrient deficiencies, especially for trace elements/micronutrients, and to monitor crop growth and performance.

Deep banding of fertiliser is often the preferred application method for lupin in WA, but alternatives include: broadcasting and incorporating; drilling pre-seeding; or splitting fertiliser applications so lower rates are in contact with the seed (not recommended for trace elements).

The Grains Research and Development Corporation (GRDC) has made investments into research by the Department of Primary Industries and Regional Development (DPIRD) – formerly the Department of Agriculture and Food Western Australia (DAFWA) – and Murdoch University in the project 'Making better fertiliser decisions for cropping systems in Western Australia' highlighting that response curves allowing advisers to understand site-specific, best management fertiliser application practices are needed to achieve optimal economic, social and environmental outcomes for lupin production.⁵

This means complying with the International Plant Nutrition Institute (IPNI 2012) 4R Nutrient Stewardship concept of – right source, right rate, right time and right place.

4.2 Soil tests

For WA soils, it is valuable to conduct pre-sowing soil tests to help determine any fertiliser use and application rates for lupin crops.

A standard soil test report provides information about:

- Soil type
- Organic carbon (C)
- Soil pH (measured in calcium chloride (CaCl₂) or water)
- Available P, K
- Extractable micronutrients (diethylenetriaminepentaacetic acid (DTPA), copper (Cu), Zn and Mn)
- Phosphorus buffering index (PBI)
- Cation exchange capacity (CEC)
- Aluminium (Al) level
- Soil salinity: electrical conductivity (EC) and salt level (percent of Na).

Working out the lupin crop response relationship from using fertiliser on a range of soil types (including sand, duplex, gravels and loams) in various rainfall zones across the WA grainbelt is complex.

WA researchers are contributing data to the GRDC-funded Making Better Fertiliser Decisions for Cropping Systems in Australia (BFDC) National Database that can be found [here](#). This is designed to help grain growers and advisers determine the response to rates of nutrients to apply to crops using locally-defined soil test calibration curves. The database includes field trial results from more than 1890 WA experiments carried out from 1966 to 2010. These include 444 trials for P, 34 for K and

MORE INFORMATION

GRDC Fact Sheet 'Soil testing for crop nutrition': www.grdc.com.au/GRDC-FS-SoilTestingW

Australian soil fertility manual: www.publish.csiro.au/pid/1998.htm

BFDC National Database: www.bfdc.com.au

⁵ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

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30 for S in lupin. Part of this project has led to the development of ‘critical ranges’ for combinations of nutrients, crops and soils.⁶

These are the range of soil test values that can be used to determine if a nutrient is deficient or adequate and are outlined in Tables 1 and 2.⁷

Table 1: Summary table of critical values (milligrams per kilogram) and critical ranges for the 0-10 cm soil sampling layer. Results derived mostly from post-1994 experiments to reflect current cropping practices.⁷

Nutrient	Crop	Soil types	Critical values (mg/kg)	Critical range (mg/kg)
P	Wheat	Grey sands	14	13–16
		Other soils	23	22–24
	Lupin	Grey sands in northern region	8	6–12
		Yellow sands in northern region	22	21–23
		Grey sands in southern region	12	10–15
		Yellow sands in southern region	30	25–37
Canola	All	19	17–25	
K	Wheat	All	41	39–45
		Yellow sands	44	34–57
		Loams	49	45–52
		Duplexes	41	37–44
	Lupin	Grey sands	25	22–28
	Canola	All	44	42–45
S	Wheat	All	4.5	3.5–5.9
	Lupin	All	na	na
	Canola	All	6.8	6.0–7.7
N	Wheat	All	15A	13–16
	Canola	All	36A	28–46

^A Critical values were poorly defined and should be used with caution, na – not available.

(SOURCE: DAFWA/Murdoch University)⁹

⁶ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

⁷ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

⁸ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

⁹ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

Table 2: Summary table of critical values (mg/kg) and critical ranges for the 0-30 cm sampling layer¹⁰

Nutrient	Crop	Critical values	Critical range
P	Wheat	11	10–11
	Lupin	9	8–10
	Canola	na	na
K	Wheat	na	na
	Lupin	na	na
	Canola	31	28–34
S	Wheat	4.6	4.0–5.3
	Lupin	na	na
	Canola	7.1	6.7–7.5

na – not available.

(SOURCE: DAFWA/Murdoch University)¹¹

The soil test critical value is the level required to achieve 90 percent of crop yield potential. The critical range indicates the reliability of the test.

As outlined in GRDC’s Fact Sheet ‘Soil testing for crop nutrition’, the narrower the range, the more reliable the result.¹²

If the soil test value is less than the lower limit, the sampling site is likely to respond to nutrient application.

If the value is above the critical range, fertiliser would generally be applied only to maintain soil levels.

But for soil test values within the range, a crop response is more uncertain and application decisions will need to take into account the costs and benefits for a particular season (including consideration of fertiliser and commodity prices).¹³

Figure 1 shows that a crop response relationship between soil test value and yield increase (tonnes per hectare) to an increase in soil test value can be worked out from a soil test. From the relationship, a critical value and critical range can be defined.¹⁴

¹⁰ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

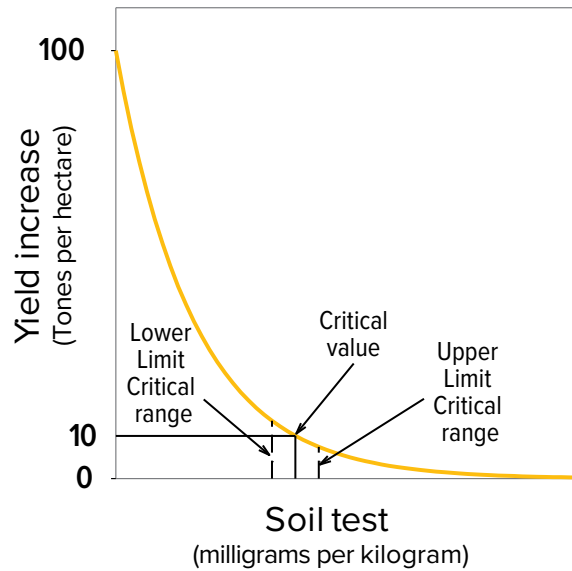
¹¹ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

¹² GRDC (2014) Fact Sheet – Soil testing for crop nutrition (western region), www.grdc.com.au/GRDC-FS-SoilTestingW

¹³ GRDC (2014) Fact Sheet – Soil testing for crop nutrition (western region), www.grdc.com.au/GRDC-FS-SoilTestingW

¹⁴ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

Figure 1: Crop response relationship can be seen between soil test value and yield increase (tonnes per hectare). This can be worked out from a soil test and from the relationship, a critical value and critical range can be defined.



(SOURCE: Geoff Anderson, DAFWA/Murdoch University)

BFDC researchers from DPIRD and Murdoch University say there is clear evidence of the value of increasing soil sampling depth in WA soils to 30 cm rather than 0-10 cm, as is common practice (especially for K).

Where relationships can be defined, the research group has made recommendations about critical soil test values for 0-10 cm sampling depth.

But it warns users to be aware that often the soil test values in the 0-10 cm layer are not reliable predictors of likely crop response to a nutrient. Also, soil test critical values can vary between soil types for tests to a 0-10 cm depth.

Greater frequency of sampling for the 0-30 cm depth will be more useful when using soil tests for predicting the need for fertiliser, especially for no-till cropping systems in WA.¹⁵

¹⁵ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

4.3 Diagnosing nutrient deficiencies

Figure 2: Common symptoms of nutrient deficiencies in narrow leaved lupin.

SYMPTOM	LOCATION											
	OLD LEAVES				MIDDLE TO NEW LEAVES				TERMINAL SHOOTS			
Chlorosis												
Complete	★	-	-	-	-	-	★	-	-	★	-	-
Mottled	-	-	★	-	-	-	★	-	-	-	-	-
Margins	-	-	-	-	-	-	-	-	★	-	-	-
Cotyledons	★	★	-	-	-	-	-	-	-	-	-	-
Necrosis												
Complete	-	★	-	-	-	-	-	-	-	-	-	-
Distinct areas	-	-	-	★	-	-	-	★	-	-	-	-
Margins	-	-	-	-	★	-	-	-	★	★	-	-
Tips	-	★	★	-	-	★	-	-	★	★	★	★
Pigmentation within necrotic or chlorotic areas												
Brown	-	-	-	★	★	-	-	★	★	★	-	-
Red	-	-	-	★	★	-	-	-	-	-	-	-
Purple	-	-	-	-	-	-	-	-	★	-	-	-
White	-	-	-	-	-	★	-	-	-	★	-	-
Malformation of leaflets												
Curled or twisted	-	★	-	-	★	-	-	-	-	-	-	-
Needle-like	-	-	-	-	★	★	★	-	-	-	-	★
Bent & disorientated	-	-	-	-	-	-	-	★	-	-	★	★
Water-stressed	-	★	-	-	-	-	-	-	-	-	-	-
Water-soaked	-	-	-	-	-	-	-	-	★	-	★	-
Malformation of leaves												
Umbrella formation	-	-	-	-	-	-	-	-	-	-	-	★
Claw formation	-	-	-	-	★	-	-	-	★	-	★	-
Rosetting	-	-	-	-	-	★	★	★	-	-	★	-
Leaf fall	-	-	★	-	★	-	-	-	-	-	-	-
Leaf & petiole fall	-	★	-	-	-	-	-	-	-	-	-	-
Petiole collapse	-	-	-	-	-	-	-	-	-	-	-	★
Root distortion	-	-	-	-	-	-	-	-	-	-	★	★
	N	P	K	Mg	K	Mg	S	Zn	Mn	Fe	B	Ca

(SOURCE: DAFWA)

Figure 3: Common symptoms of nutrient deficiencies in albus lupin.

SYMPTOM	LOCATION											
	OLD LEAVES			MIDDLE TO NEW LEAVES						TERMINAL SHOOTS		
Chlorosis												
Complete	★	★	★	-	★	-	-	★	-	-	-	-
Mottled	-	★	-	-	-	-	★	★	-	-	-	-
Interveinal	-	-	★	★	-	★	★	-	-	-	-	-
Intraveinal	★	-	-	-	-	-	-	-	-	-	-	-
On margins	-	-	★	-	-	-	-	-	-	-	-	-
Necrosis												
Complete	-	★	-	-	-	-	-	-	-	-	-	-
Distinct areas	-	-	★	-	★	★	-	-	-	-	-	-
Margins	-	-	-	★	-	-	★	-	-	-	-	-
Tips	-	-	-	★	-	-	-	-	-	★	★	★
Pigmentation within necrotic or chlorotic areas												
Green	-	★	-	-	-	-	-	-	-	-	-	-
Brown	-	★	★	-	★	-	★	★	-	-	-	-
Red	-	-	-	-	-	-	★	-	-	-	-	-
Bronze	-	-	-	★	-	★	★	-	-	-	-	-
Malformation of leaflets												
Miniaturised	-	-	★	-	-	-	-	-	-	-	-	-
Boat-like	-	-	-	-	-	-	★	★	★	-	-	-
Spike-like	-	-	★	-	-	-	-	-	-	-	-	-
Water-soaked	-	-	-	-	-	-	-	-	-	-	★	-
Malformation of leaves												
Umbrella formation	-	-	★	★	-	★	-	-	-	-	★	-
Claw formation	-	-	-	-	-	-	★	★	-	-	-	-
Star formation	-	-	-	★	-	-	-	-	-	★	-	-
Rosetting	-	-	-	-	-	★	-	-	-	-	★	-
Leaf fall	-	★	-	-	-	-	-	-	-	-	-	-
Petiole collapse	-	-	-	-	-	-	-	-	-	-	-	★
Root distortion	-	-	-	-	-	-	-	-	★	-	★	★
	N	P	K	Mg	S	Zn	Mn	Fe	Cu	B	Ca	

(SOURCE: DAFWA)

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Visual symptoms of any nutrient deficiency in lupin crops can appear similar to those seen in other pulses or those caused by damage from herbicides, insects, disease or adverse environmental conditions, such as moisture stress, soil constraints or extreme temperatures.

It should also be noted that considerable yield loss can occur without the appearance of any visual symptoms in-crop. This means it is advisable to confirm diagnosis of any suspected nutrient deficiencies in lupin using plant tissue testing.

Researchers in Western Australia have developed guidelines for assessing a range of potential nutrient deficiencies in narrow leafed and albus lupin crops and these are outlined in Figures 2 and 3.¹⁶

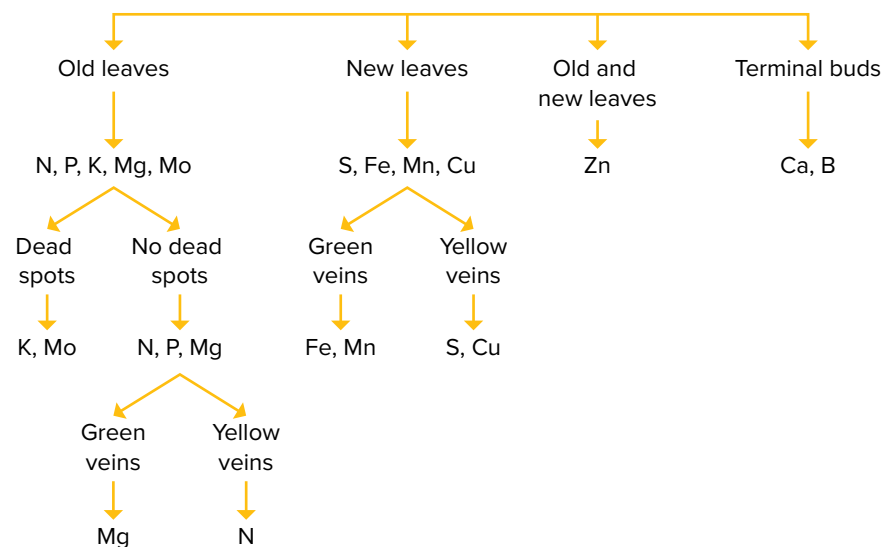
More information about diagnosing nutrient deficiencies is also available on the DPIRD-GRDC MyCrop hub at: <https://www.agric.wa.gov.au/mycrop>

Tips for identifying nutrient deficiencies in lupin crops in the western region include:

- Know what a healthy plant looks like in order to recognise symptoms of distress
- Determine what the affected areas of the crop look like (i.e. are they discoloured, dead, wilted or stunted?)
- Identify the pattern of symptoms in the field (i.e. patches, scattered plants, crop perimeters)
- Assess affected areas in relation to soil type (i.e. pH, colour, texture) or elevation
- Check individual plants for more detailed symptoms (i.e. stunting, wilting).

Considerations when diagnosing nutrient disorders in pulse crops are outlined in Figure 4.

Figure 4: Flow chart for the identification of deficiency symptoms.



(SOURCE: T Reddy, G Reddi (1997) Mineral nutrition, manures and fertilizers. In Principles of Agronomy, pp. 204-256. Kalyani Publishers, Ludhiana, India)

It should be noted that if more than one nutrient deficiency is present in a lupin crop, typical visual symptoms may not occur. If two nutrients are simultaneously deficient, symptoms may differ from the deficiency symptoms of the individual nutrients.

Micronutrients are often used by plants to process other nutrients, or work together with other nutrients, so a deficiency of one may look like deficiency of another.

¹⁶ Snowball, K. and Robson, A.D. University of Western Australia (1986) Symptoms of nutrient deficiencies, <http://trove.nla.gov.au/work/18831182?q&versionId=22106141>

i MORE INFORMATION

DPIRD-GRDC MyCrop: <https://www.agric.wa.gov.au/mycrop/monitor-plant-nutrition-levels>

GRDC Hot Topic 'Micronutrients in the western region': <https://grdc.com.au/Media-Centre/Hot-Topics/Micronutrients-in-the-western-region>

GRDC 2016 Grains Research Update paper '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>

4.4 Plant tissue testing

Plant tissue tests can be used to determine if lupin crops are deficient in nutrients, particularly trace elements/micronutrients.

Tissue testing reflects what the plants can take up from the soil at the time of sampling.

These tests provide an accurate diagnosis of nutrient deficiencies, particularly where it is difficult to rely on visual symptoms in the paddock. Single element symptoms can often be confused with each other, or with disease or other stresses.

Also, once deficiency symptoms can be seen, plant growth may have already slowed and a yield penalty may have occurred.

In some cases, plants will not show obvious signs of a deficiency, even though crop growth may be restricted.

A stem test for Mn is available at early flower budding to diagnose the likelihood of Mn deficiency during grain fill that can lead to 'split' seed or 'shriveled' seed if not corrected.

Regular testing also facilitates longer-term monitoring of crop growth and performance.

The most useful elements for plant tissue analysis in WA crops include P, Mn, Cu, Zn and S.

Table 3 shows the elements that can be provided in a standard plant tissue test report and recommended minimum plant nutrient levels for WA lupin (and other pulse) crops.

Table 3: Recommended minimum plant nutrient levels for a range of pulse crops, during vegetative stages (seedling to budding)

Plant nutrient	Faba beans	Lupin	Field peas
Phosphorus (%)	0.35–0.45	0.2–0.3	0.25–0.4
Nitrogen (%)	4.0	4	-
Potassium (%)	2.0–2.5	1.2–1.5	1.5–2.0
Sulfur (%)	-	0.2–0.25	-
Magnesium (%)	0.2	-	0.2
Calcium (%)	0.6	-	0.6
Micronutrient (or trace elements)			
Manganese (Mn)			
mg/kg	20–25	17–20	20–30
Iron (Fe) ppm	-	-	-
Copper (Cu) mg/kg	>3.0	>1.2	>3.0
Zinc ppm	>20–25	>12–14	20–30
Boron mg/kg ppm	10	15	10

Young leaves are recommended for micronutrient testing if deficiency suspected.
(SOURCE: DAFWA)¹⁷

17 DPIRD (2016) Monitor plant nutrition levels, <https://www.agric.wa.gov.au/mycrop/monitor-plant-nutrition-levels>

4.5 Phosphorus (P)



Figure 5: Leaves on severely phosphorus deficient lupin plants bend or become twisted before dying.

(SOURCE: Alan Robson)

Phosphorus is an essential component of cell membranes and plant genetic material and helps in the energy storage and transfer system in plant cells.

Long-term continual use of P fertiliser across much of the WA grainbelt has meant acute P deficiency in lupin and other broadacre crops is rare.

The exception can be on highly acidic and high phosphorus buffering index (PBI) soils in the Darling Ranges.

In recent years, many WA growers have diverted P fertiliser spending to lime application because their soils have adequate soil P levels.

As shown in Table 4 below, soil P critical values for lupin (in the 0-10 cm layer) range from 8 milligrams per kilogram in the northern region (grey sands) to 22 mg/kg in the southern region (yellow sands).

The soil P critical value for lupin crops deeper in the profile (in the 0–30 cm layer) is 8 mg/kg, in a range of 8 to 10 mg/kg.¹⁸

¹⁸ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

Table 4: Lupin soil P test critical values and ranges (mg P/kg) for grey sands and yellow sands using the 0-10 cm soil layer and for all soil types using the 0-30 cm soil layer.¹⁹

Region and soil types	Number of experiments	Critical value ^A	Critical range ^B	r ² ^C
NAR grey sands 0-10 cm	22	8	6–12	0.27
NAR yellow sands 0-10 cm ^D	46	22	21–23	0.91
CAR and SAR grey sands 0-10 cm	22	12	10–15	0.73
CAR and SAR yellow sands 0-10 cm ^D	46	30	25–37	0.46
All 0-30 cm (mg P/kg) ^E	62	9	8–10	0.79

^ASoil test value (mg P/kg) at 90 percent of predicted maximum grain yield, ^B95 percent chance that this range covers the critical soil test value ^C r² is the percentage variation in the data explained by the fitted regression line, ^Dyellow sands with PBI=14, ^Eall soils. NAR, Northern Agricultural region, CAR, Central Agricultural region, SAR Southern Agricultural region
(SOURCE: DAFWA/Murdoch University)²⁰

Critical lupin plant P levels vary with plant age and size.

At the vegetative stage and up to 80 days after sowing, the critical levels are 0.27–0.37 percent and at 80 to 140 days after seeding, critical levels are 0.13–0.23 percent. This can be assessed with plant tissue tests if diagnosis of deficiency is required. The required seed P concentration for early seedling vigor is 0.25 percent and this can be assessed by accredited seed testing laboratories.

If there is P deficiency, this is often transitory and compounded by dry soil. Symptoms tend to disappear when topsoil becomes wet after rainfall.²¹

The common symptoms of P deficiency in WA narrow leafed lupin crops include:

- » Smaller, later flowering plants
- » Narrow stems and petioles
- » Fewer lateral branches
- » Leaves dying back from the tips and dropping
- » Upward angled petioles and leaflets (upright appearance)
- » Older leaves turning grey-green and drooping.²²

19 Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

20 Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

21 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing phosphorus deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-narrow-leafed-lupins>

22 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing phosphorus deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-narrow-leafed-lupins>



Figure 6: Low phosphorus levels in lupin crops can be expressed by smaller plants with thinner stems and fewer laterals, as shown on left.

(SOURCE: DAFWA)

Management of any P deficiency in lupin crops starts with application of P fertiliser, based on the critical values found from soil or plant tissue test results.

The best way to apply P fertiliser to lupin crops depends on rainfall and the capacity of the soil to retain P, measured as soil test PBI, and recommendations include:

- » On low PBI sandy soils, separate seed and fertiliser to avoid toxicity
- » On very high PBI soils, apply P with the seed
- » Topdressing or deep banding on sandy soils
- » On most soils, drill P with or near the seed.²³

Research has found that placing fertiliser with the lupin seed at sowing at levels higher than 15 to 20 kgP/ha can reduce crop emergence. Damage will be greater in drier soils.

Banding P below the seed can reduce damage without reducing availability to the plant.

Typically, banding fertiliser below the seed leads to higher yields than placing it with the seed.

Soil P levels influence the rate of nodule growth. The higher the P level, the greater the nodule growth.

Calculating how much P to apply should be done with profitability in mind and Tables 4-6 can be used as a guide to superphosphate application rates for low, medium and high PBI soils.²⁴

²³ DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing phosphorus deficiency in narrow-leaved lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-narrow-leaved-lupins>

²⁴ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

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Table 5: Calculating the most profitable rate of superphosphate (kilograms per hectare) to apply at sowing for optimum lupin production on low phosphorus retaining soils with Phosphorus Buffering Index (PBI) <2

These soils include leaching grey and yellow sands, such as those found on the Swan Coastal Plain, the Eradu sandplain, the south coast, in the midlands and sometimes in lower rainfall cropping areas.

Price ratio	Optimum relative yield (%)	Colwell soil test P for top 10 cm of soil (mg/kg)											
		< 2	4	6	8	10	12	15	20	25	30	35	40
Optimum rate of phosphorus (kg/ha) to drill with seed while sowing the next lupin crop													
50	66.7	12	10	7	1	0	0	0	0	0	0	0	0
40	73.3	15	12	9	4	0	0	0	0	0	0	0	0
30	80.0	18	15	12	7	1	0	0	0	0	0	0	0
20	86.7	22	20	17	12	6	2	0	0	0	0	0	0
10	93.3	30	28	24	19	13	10	3	0	0	0	0	0
7	95.3	34	32	28	23	17	14	7	1	0	0	0	0
5	96.7	38	35	32	27	21	17	10	5	2	0	0	0
4	97.3	40	38	35	30	23	20	13	7	5	1	0	0
3	98.0	43	41	38	33	27	23	16	10	8	5	0	0
2	98.7	48	45	42	37	30	28	20	15	12	9	5	0

Note: table prepared by Bill Bowden, Chris Shedley, Steve Burgess and Craig Scanlan from DAFWA.²⁵

Table 6: Calculating the most profitable rate of superphosphate (kg/ha) to apply at sowing for optimum lupin grain production on moderate to medium phosphorus retaining soils with PBI 2 to 15.²⁶

These soils can be divided into two groups: soils with PBI values from 2 to 8, including sandy loams and duplex soils that previously grew York gum, jam, mallee, white gum and tamma; and soils with PBI values from 9 to 15, including those that were marginally acidic to neutral and previously grew salmon gum and York gum.

Price ratio	Optimum relative yield (%)	Colwell soil test P for top 10 cm of soil (mg/kg)											
		< 2	4	8	12	16	20	25	30	35	40	45	50
Optimum rate of phosphorus (kg/ha) to drill with seed while sowing the next lupin crop													
50	66.7	12	11	9	5	0	0	0	0	0	0	0	0
40	73.3	15	14	11	7	2	0	0	0	0	0	0	0
30	80.0	18	17	15	10	5	0	0	0	0	0	0	0
20	86.7	22	21	19	15	10	5	0	0	0	0	0	0
10	93.3	30	29	27	22	17	12	6	1	0	0	0	0
7	95.3	34	33	31	26	21	16	10	5	1	0	0	0
5	96.7	38	37	35	30	25	20	13	8	5	2	0	0
4	97.3	40	39	37	33	28	22	16	11	7	5	1	0
3	98.0	43	43	40	36	31	26	19	14	10	8	5	0
2	98.7	48	47	45	40	35	30	23	18	15	12	9	5

²⁵ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

²⁶ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

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Table 7: Calculating the most profitable rate of superphosphate (kg/ha) to apply at sowing for optimum lupin grain production on high phosphorus retaining soils with PBI 16 to 35.²⁷

These soils include those that originally grew salmon gum and gimlet, acidic sandy loams and acidic loams of the eastern grainbelt and jarrah–marri gravely loams on the western margins of the grainbelt. They also include jarrah and karri loams and clay loams and clays of the river flats, and the white gum and dryandra loams in lower rainfall areas.

Price ratio	Optimum relative yield (%)	Colwell soil test P for top 10 cm of soil (mg/kg)											
		< 2	5	10	15	20	25	30	35	40	45	50	55
Optimum rate of phosphorous (kg/ha) to drill with seed while sowing the next lupin crop													
50	66.7	12	12	11	9	7	1	0	0	0	0	0	0
40	73.3	15	15	14	12	9	4	0	0	0	0	0	0
30	80.0	18	18	17	15	12	7	0	0	0	0	0	0
20	86.7	22	22	21	20	17	12	5	0	0	0	0	0
10	93.3	30	30	29	28	24	19	12	5	1	0	0	0
7	95.3	34	34	33	31	28	23	16	8	5	1	0	0
5	96.7	38	38	37	35	32	27	20	12	8	5	2	0
4	97.3	40	40	39	38	35	30	22	15	11	7	5	2
3	98.0	43	44	43	41	38	33	26	18	14	10	8	5
2	98.7	48	48	47	46	42	37	30	22	18	15	12	9

²⁷ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

i MORE INFORMATION

Liebe Group 'Trials of Mn fertilisers':
<http://www.farmtrials.com.au/search.php?query=wa+lupins+deficiency>

DPIRD Lupin Diagnostic tool:
<https://www.agric.wa.gov.au/lupin-diagnostic-tool>

SARDI 2016 GRDC Update Paper '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>

4.6 Manganese (Mn)

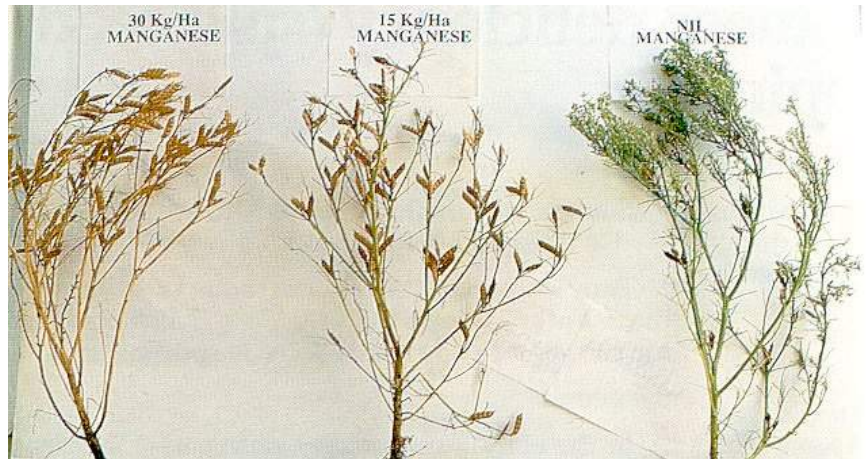


Figure 7: Symptoms of manganese deficiency in lupin plants include plants with straggly growth and delayed maturity.

(SOURCE: DAFWA)

Manganese is part of many metabolic processes in lupin plants and important in the production of chlorophyll.

Lupin crops are typically able to access Mn that is unavailable to cereal crops on WA's high P-fixing soils, but deficiencies tend to occur on very low Mn content sandy soils – especially in dry seasons with a dry spring finish.

In WA, this problem occurs mainly in slightly acidic grey sands, yellow sands and gravelly sands common in the south west and west midlands regions, where the average annual rainfall is higher than 450 mm.

In these areas, grain yields of narrow leafed lupin crops can be significantly reduced due to Mn deficiency, which causes grain to split (called split seed disorder) and sometimes discolour around the seed margins.



Figure 8: Low manganese in lupin can lead to seeds splitting through the seed coat and being shriveled.

(SOURCE: DAFWA)

Research into Mn has shown yield penalties of up to 70 percent from split seed disorder. This problem also occurs in lower rainfall parts of the grainbelt in some seasons, usually on coarser, deeper, more leached sands.²⁸

Incidence and severity of split seed disorder in WA lupin crops will vary according to the maturity of the variety, planting date, amount of rainfall received during the growing season and soil type.

High pH soils (above pH 7) tend to have lower Mn availability to lupin crops than soils with lower pH, making Mn deficiency more likely to occur.

Lime application to raise soil pH has been found to induce split seed disorder on some soils in some years in WA.²⁹

Narrow leafed lupin has a poor ability to accumulate Mn in grain and concentrations are usually much lower than those in albus varieties.

South Australian research indicates adequate Mn levels in youngest fully open leaf (YOL) and main stem in legumes (including lupin) are about 20 mg/kg (identified through plant tissue testing). For these tests, about 20–30 lupin stems/test are required.³⁰

A main stem analysis of lupin can be used to diagnose any Mn deficiency at flowering.

Common symptoms of Mn deficiency in narrow leafed lupin crops include:

- » Plants with straggly growth and delayed maturity with 're-greening'
- » Dropped leaves
- » Re-shoot leaves with a 'tufty-type' growth on branches
- » Seeds split through the seed coat
- » Discoloured seed around the margins
- » Small, shrivelled seed
- » Dirty brown patches on leaves.³¹

Management of Mn deficiency in WA lupin crops starts with early sowing of early maturing varieties to reduce the risk of split seed developing when seed fills and matures before soil moisture is exhausted in spring.

Split seed disorder can be treated by applying Mn fertiliser to soil (with rates based on soil type) and/or using sprays on lupin foliage (typically with Mn sulfate or a range of other Mn products). Foliar applications of about 1 kgMn/ha in 75–100 Litres of water usually corrects the deficiency – if sprayed when pods on main stem are about 2–2.5 cm in length. Soil-applied fertiliser has good residual value and can last for several years. Foliar sprays supply Mn only to a particular crop in a particular year.³²

28 O'Callaghan, C (2010) Overcoming manganese deficiency, Liebe Group, Online Farm Trials final report, <http://www.farmtrials.com.au/search.php?query=wa+lupins+deficiency>

29 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing manganese deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-narrow-leafed-lupins>

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

31 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing manganese deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-narrow-leafed-lupins>

32 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cqi/viewcontent.cqi?article=1009&context=bulletins>

Recommendations for managing Mn deficiency in lupin include:

- » A foliar spray at pod length 2—2.5 cm on the main stem (to prevent split seed)
- » Mn sulphate drilled at seeding at a rate of 25—30 kg/ha (northern grey/ yellow sands and gravels; south coast sands)
- » Double application, if necessary
- » Mn sulphate deep banded before seeding at 15—20 kg/ha (west midlands white sands; sandy gravels).³³

Manganese is immobile in the soil and compared to drilled fertiliser, topdressed Mn can be 25—50 percent less effective and deep banded Mn up to twice as effective as drilled product in dry spring weather.

On potentially Mn-deficient soils (mainly light sands) in WA, Mn can be applied as Mn sulphate fertiliser or a compound fertiliser containing Mn, deep banded under the seed and/or provided as a foliar spray when first pods are 2.5 cm in length and secondary stems have almost finished flowering.³⁴ A repeat application may be required to cover the third or fourth order lateral flowers and pods where there is an extended growing season.

Foliar spraying of Mn sulphate at a rate of 4 kg/ha in 75—100 L of water directly to lupin crops is an effective method of controlling split seed disorder.

Other compounds (for example, Mn chelate) can be effective, provided the rate of Mn is equivalent to that in 4 kg/ha of Mn sulfate (1 kg/ha of elemental Mn).

Research trials in WA have found that increasing the rate will not significantly increase the effectiveness of the foliar spray.³⁵

Foliar sprays sometimes fail, as the development stage of the seed at the time of spraying is critical. It is advised to spray when the pods on the main stem are 2—3 cm in length and secondary stems have almost finished flowering. Using aerial application can avoid mechanical damage to the crop.³⁶

Testing lupin seed for Mn concentrations can be important when retaining grain for subsequent sowing, as low levels can significantly hamper germination and crop establishment.

Benchmark Mn seed concentration is 13 mg/kg and it is recommended to use planting seed from lupin crop areas that have been fertilised with Mn.³⁷

33 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing manganese deficiency in narrow-leaved lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-narrow-leaved-lupins>

34 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

35 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

36 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

37 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

4.7 Molybdenum (Mo)



Figure 9: Molybdenum deficiency in narrow leaved lupin crops can affect rhizobia ability to fix nitrogen.

(SOURCE: Alan Robson)

This trace element is essential for rhizobia to fix N, as it is part of the enzyme nitrate reductase that converts soil nitrate-N to nitrite-N in cells for plant use.

Lupin crops are often grown in WA's acid wadjil yellow sandplain soils, which are commonly low in Mo.

Molybdenum is strongly retained by soils at low pH (below 5) and is usually deficient only in these low pH soils.

Management of Mo deficiency in WA lupin crops includes:

- » Using seed with a known high level of Mo
- » Raising the pH of the soil
- » Coating the seed with Mo fertiliser
- » Using an in-crop compound fertiliser containing Mo
- » Applying Mo with herbicide.³⁸

Coating seed with Mo fertiliser is one way to supply Mo to deficient lupin seeds, but experience in some areas of WA indicates it is best supplied to crops in a compound fertiliser. Coating seeds with a solution of sodium Mo has resulted in nodulation problems in some areas, possibly due to the Mo salt killing the *Bradyrhizobium* bacteria in the inoculum. The molybdate solution (5–6 percent Mo) is also alkaline (pH 9–10), with potential to cause a breakdown of the seed dressing used to control Brown leaf spot (*Pleiochaeta setosa*) disease.³⁹

38 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

39 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

4.8 Nitrogen (N)



Figure 10: Nitrogen deficiency can lead to nodule dysfunction in albus and narrow leafed lupin crops and adding small amounts of N can be beneficial.

(SOURCE: Alan Robson)

An essential component of amino acids and proteins, N is important in the production of chlorophyll for synthesis.

Demand for N by lupin (and other broadacre crops) is related to actual yield, which is determined by seasonal conditions and the amount and timing of growing season rainfall.

Typically, a well-nodulated lupin crop obtains its total N needs from the atmosphere by symbiotic N fixation with rhizobia.

Applying N fertiliser to lupin crops in WA typically does not increase grain yields or protein.⁴⁰

Small amounts of N (about 10 kg/ha) are sometimes applied by growers at sowing to boost seedling growth, particularly in the colder areas of the central and southern grainbelt where plants may be slow to nodulate. This amount has been found to not inhibit lupin plant nodulation, but can stimulate weed growth without clear evidence of a yield benefit. Applying more than 10 kgN/ha on WA lupin crops can delay nodulation and N fixation.⁴¹

A major benefit of including lupin crops in a rotation is to lift soil N levels and availability for subsequent crops.

⁴⁰ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

⁴¹ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

i MORE INFORMATION

DPIRD-GRDC MyCrop 'Diagnosing Potassium Deficiency': <https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-narrow-leafed-lupins>

CSBP 'Lime and K response trial results': <http://www.farmtrials.com.au/search.php?query=p+deficiency+lupins>

4.9 Potassium (K)



Figure 11: Low potassium levels tend to lead to twisted and claw-shaped middle and younger leaves on severely deficient lupin plants.

(SOURCE: DAFWA)

Potassium is an essential plant macronutrient, used in key processes of photosynthesis, transport of sugars, enzyme activation, maintenance of plant turgor and regulation of stomata.

Potassium deficiency can lead to inefficient plant nutrient and water uptake and increased vulnerability to stresses such as drought, waterlogging, diseases and insect pests.

Many sandy, acid soils in WA, especially in high rainfall areas, have become deficient in K.⁴²

But lupin crops grown on these soils tend to not be adversely affected because often K fertiliser is applied to other crops in the rotation and this provides sufficient residual K for lupin crops.

As shown in Table 8, soil test data for WA lupin indicates the critical value for achieving 90 percent of maximum yield on grey sands in the northern region is 25 mgK/kg, in a range of 22–28 mgK/kg.⁴³

Critical K levels will vary with plant age and size, but K concentration in whole shoots below 3.1 percent and 0.9 percent at 28 and 140 days after seeding, respectively, can indicate deficiency.⁴⁴

Table 8: Lupin soil potassium (K) test critical value and range (milligrams K per kilogram) for grey sands when sampling layer was 0-10 cm.⁴⁵

Soil type	Number of experiments	Critical value ^A	Critical range ^B	r ^{2C}
Grey sands	32	25	22-28	0.53

^ASoil test value (mg K/kg) at 90 percent of predicted maximum grain yield, ^B95 percent chance that this range covers the critical soil test value ^Cr² is the percentage variation in the data explained by the fitted regression line.

(SOURCE: DAFWA/Murdoch University)

42 Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

43 Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

44 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing potassium deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-narrow-leafed-lupins>

45 Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

Research on WA's deep sandy soils has shown that K fertiliser applied at a rate of about 50 kg/ha can have a residual value of at least two years before re-application is necessary, especially in deep sands (but this may not be as reliable for duplex soils).⁴⁶

Trials on sandplain soils have shown the rooting depth of narrow leafed lupin and sandplain lupin is important for recycling K from the subsoil to the topsoil.⁴⁷

Other national trials have found the roots of narrow leafed lupin and yellow lupin take up less K from the soil than wheat and canola roots, but use the K more effectively within the plant to produce shoots. This highlights that lupin plants appear to have a lower external efficiency for K uptake, but a higher internal efficiency for K use.⁴⁸

Signs of any K deficiency in WA lupin crops include:

- Patches of poor growth among patches of better growth in paddocks
- Smaller, thinner, paler plants
- Some or all leaflets chlorotic or fallen off Middle and younger leaves twisted and claw shaped
- Petioles intact.⁴⁹



Figure 12: *In-crop signs of low potassium include smaller thinner plants, on right, that are more susceptible to disease.*

(SOURCE: DAFWA)

Topdressed or banded K fertilisers can help to manage any K deficiency in lupin crops.

Potassium deficiency management recommendations for WA lupin crops include:

- » Apply K chloride and K sulfate based on soil test/plant tissue test results
- » K chloride contains 50 percent K, K sulfate contains 41.5 percent K and each is equally effective per unit of applied K
- » Avoid drilling K chloride with the seed
- » It is best to topdress K four weeks after sowing.⁵⁰

46 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

47 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

48 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

49 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing potassium deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-narrow-leafed-lupins>

50 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

i MORE INFORMATION

DPIRD-GRDC MyCrop: <https://www.agric.wa.gov.au/mycrop/diagnosing-sulphur-deficiency-narrow-leafed-lupins>

i MORE INFORMATION

GRDC 2016 Updates Paper '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>

GRDC Hot Topic 'Micronutrients in the western region': <https://grdc.com.au/Media-Centre/Hot-Topics/Micronutrients-in-the-western-region>

DPIRD 'Monitor plant nutrition levels': <https://www.agric.wa.gov.au/mycrop/monitor-plant-nutrition-levels>

4.10 Sulfur (S)

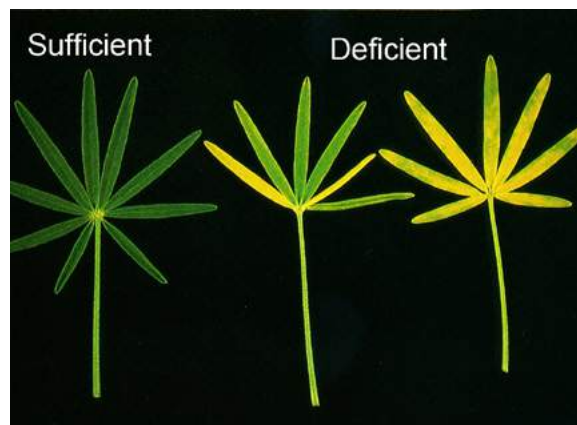


Figure 13: When there is sulfur deficiency in lupin, as shown on right, older leaflets drop and have total or mottled chlorosis.

(SOURCE: Alan Robson)

Sulfur is an essential part of some amino acids in lupin plants, including methionine, cystine and cysteine. If there is deficiency, the quality of grain proteins and animal feed value can fall.

Sulfur deficiency is not typically seen in WA lupin crops. This is mainly because S fertilisers are applied to other crops in the rotation that are more prone to S deficiency and this leaves sufficient residual levels for lupin crops.

Also, historic widespread use of fertilisers containing S in this State (such as superphosphate) has generally provided adequate long-term soil S reserves for lupin plant growth.

Recommended critical S concentrations in lupin plants are 0.28 percent (young leaves), 0.07 percent (stems) and 0.15 percent (whole shoots) and critical N:S ratio for S deficiency is 15.⁵¹

The BFDC soil test database has found the 0-10 cm soil test is a poor guide for S soil critical levels, as plants can access S reserves at depth. It says lupin crops have lower S requirements than wheat or canola.⁵²

When considering fertilisers, it is worth noting that single superphosphate contains about 10.5 percent S and a range of other fertiliser products contain S as a by-product. These fertilisers help maintain adequate S levels in soils for cropping. Gypsum is commonly used on WA canola crops, often at high rates of 30–500 kg/ha, and it contains about 17 percent S. This also adds to S levels in the soil for other crops, including lupin.⁵³

4.11 Trace elements/micronutrients

Despite many decades of research into trace element management, many crops across WA's agricultural area can still be deficient in one or more of these 'micro' nutrients.

Trace elements can be monitored and managed using soil and plant tissue testing, as well as reviewing soil types, crop type and seasonal conditions.

51 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing sulphur deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-sulphur-deficiency-narrow-leafed-lupins>
 52 Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University
 53 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

Deficiencies of these nutrients in crops can usually be overcome with relatively inexpensive sprays, but investing in tactics to increase soil reserves can be worthwhile.⁵⁴

4.11.1 Zinc (Zn)



Figure 14: When lupin is deficient in zinc, leaflets become bent and curled – often backwards towards the petiole.

(SOURCE: Alan Robson)

Zinc is an important component of enzymes. Many of the physiological effects caused by any Zn deficiency in lupin crops is associated with disruption of normal enzyme activity, including photosynthesis, membrane leakiness, auxin metabolism and reproduction.

Lupin crops are less susceptible to Zn deficiency than wheat or oats, although there can be incidence on newly-limed areas.

Albus lupin is more susceptible to Zn deficiency than narrow leafed lupin varieties.

Zinc fertiliser is regularly applied to cereal crops as an insurance against deficiency and has a good residual value.

While Zn deficiency in WA lupin crops is rare, symptoms include:

- » Plants with pale new leaves
- » Shortened petioles, causing a bunched appearance
- » Brown spots along the mid-ribs of pale new leaflets
- » Bent and curled leaflets, often backwards towards the petiole.

Because Zn is immobile in the plant, young shoot or young leaf sampling is most accurate to detect crop levels.

The critical concentration for the youngest open leaflet before flowering is 12–14 mg/kg, but this will vary with soil type.⁵⁵

Management of any Zn deficiency in WA lupin can include:

- » Using a foliar spray (effective only in current season)
- » Using a soil fertiliser drilled with the following crop
- » Applying any foliar sprays as soon as deficiency is detected
- » Not topdressing Zn, but deep drilling.⁵⁶

⁵⁴ Wilhelm, N, Davey, S (2016) Detecting and managing trace element deficiencies in crops. 2016 GRDC Grains Research Update paper, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Detecting-and-managing-trace-element-deficiencies-in-crops>

⁵⁵ DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing zinc deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-narrow-leafed-lupins>

⁵⁶ DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing zinc deficiency in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-narrow-leafed-lupins>

i MORE INFORMATION

DPIRD-GRDC MyCrop: <https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-narrow-leafed-lupins>

4.11.2 Iron (Fe)



Figure 15: *In the paddock, iron deficiency in lupin crops can be characterised by smaller, paler plants with chlorotic new leaves.*

(SOURCE: Alan Robson)

Iron deficiency is one of the causes of poor growth of lupin crops on some WA alkaline soils, typically those with a pH above 7 and especially when soil aeration is reduced slightly and temperatures are cold. Industry advisers recommend not growing lupin on these types of soils.

A complex series of interactions combines to reduce the availability of Fe to lupin plants and yield potential on alkaline soils tends to be less for lupin than other grain legumes.

It is advised to closely monitor lupin crops grown on fine-textured, alkaline soils that become saturated with water in winter, as these may show bright yellowing of young leaves. This is a typical symptom of Fe deficiency.

Experience in WA shows plants tend to grow out of Fe deficiency in some areas when the soil dries (improving aeration), or when temperatures increase.

But the growth of lupin roots is also impeded in alkaline soils, so in spring these plants can suffer early water stress and yield poorly.

Foliar application of Fe will reduce symptoms of deficiency and improve plant growth, but has not proven to increase grain yields.⁵⁷

Symptoms of Fe deficiency in WA lupin crops include:

- » Young leaves and new growth become yellow over the whole leaf
- » In wet conditions, brown leaf spot lesions on leaves may be present
- » Middle leaves of severely deficient plants may shrivel back towards the base of the leaflet.⁵⁸

⁵⁷ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

⁵⁸ DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing iron deficiency in narrow leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-narrow-leafed-lupins>

4.11.3 Boron (B)



Figure 16: Boron deficiency in WA lupin crops is rare, but typically expressed with shortened petioles on new growth, resulting in a cluster formation.

(SOURCE: Alan Robson)

Boron deficiency is rare in most WA crops, but is more likely to impact lupin and other broadleaf species before cereal crops.

Areas most at risk of B deficiency are sandy acidic sedimentary soils on the west coast that receive more than 600 mm annual rainfall – such as the sandplains of the Dandaragan plateau, stretching from the west midlands to Eradu.

As B is immobile in the plant, young shoot sampling is the most accurate way to monitor crop B levels.

The critical concentration for the youngest open leaflet before flowering in lupin crops is 12-15 mg/kg.⁵⁹

Critical levels at the seedling stage are not reliable because having dry or acidic topsoil will reduce B availability and as B moves through the soil, higher levels may be present in the subsoil. There is no calibrated soil test for B deficiency in lupin. Soil testing may be useful on deep sands, but subsoil testing for B levels should also be conducted on duplex soils.⁶⁰

Lupin research in this State has not shown clear shoot and grain yield responses to applied B fertiliser. A big problem for B in most crop species is that the range of B levels in soil for deficiency and toxicity for plant production is very small. Indiscriminate use of B fertiliser in lupin is not advised because toxicity problems can be induced and are difficult to ameliorate.⁶¹

Symptoms of any B deficiency in WA lupin crops include:

- » Profuse stubby lateral tap and secondary roots with a knobby end
- » Dark green new growth on the main stem and laterals
- » Thickened leaflets, partially opened with a dark green mid-rib and fur-like edges
- » Shortened petioles on new growth that result in a cluster formation
- » Dark brown leaflets that become down-curved, giving an umbrella effect
- » New growth that dies on emergence.

⁵⁹ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

⁶⁰ Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

⁶¹ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cqi/viewcontent.cgi?article=1009&context=bulletins>

Recommended management strategies for any B deficiencies include:

- » Foliar applications for fast response to minimise yield loss
- » Strategic timing of application to avoid irreversible damage
- » If B deficiency is diagnosed (by a crop tissue test) follow with a soil application.

4.11.4 Copper (Cu)

Copper is required by plants in very small amounts, but is an essential component of many enzymes that control chemical reactions – including during N fixation and development of cell wall strength in lupin. WA lupin crops tend not to suffer Cu deficiency, even when grown on soils that are Cu deficient for other crops.

This is mainly because Cu fertiliser is commonly applied to many soils as an insurance against deficiency for these species.⁶²

But in 2016, at the GRDC Grains Research Updates in the southern region, researchers from the SARDI Waite Institute warned that Cu deficiency in soils may re-surface as a problem across southern Australia in coming years due to:

- » Applications of Cu made 20–40 years ago running out
- » Increased use of N fertilisers that could increase the severity of Cu deficiency
- » Seasonal conditions and farming practices.⁶³

Although Cu deficiency is best corrected with soil applications, foliar sprays will also overcome the problem in the short term. A foliar spray of Cu (at a rate of 75–100 g Cu/ha) is cost effective (usually less than \$1/ha for the ingredient), but a second spray immediately prior to pollen formation may be necessary in severe situations.⁶⁴

Researchers from The University of Western Australia (UWA) and Newcastle University in the United Kingdom recently discovered Cu levels in the soil affect the delicate balance of microbes (archaea and bacteria) responsible for soil nitrification.

This research differs from previous studies that suggested N fertilisers played a large role in affecting these microbes.

Testing of WA soils showed a relationship between soil age and the levels of archaea and bacteria microbes. Lack of Cu was found to limit the archaea microbial population which, in turn, limited soil nitrification and led to domination of bacterial nitrification.

The findings are an important step forward in developing targeted solutions to manage nitrification in soil.⁶⁵

62 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

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

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

65 O'Donnell, A (2016) Lack of copper in ancient soil regulates nitrification, UWA, Journal 'Scientific Reports', August 2016, <http://www.news.uwa.edu.au/201608118927/research/lack-copper-ancient-soil-regulates-nitrification>

i MORE INFORMATION

GRDC Fact Sheet 'Nitrogen fixation of crop legumes: basic principles and practical management': <https://grdc.com.au/Resources/Factsheets/2014/07/Nitrogen-fixation-of-crop-legumes-basic-principles-and-practical-management>

GRDC Fact Sheet 'Maximising nitrogen availability to crops': <https://grdc.com.au/GRDC-FS-PlantAvailableNitrogen>

GRDC Hot Topic 'Break crop research': <https://grdc.com.au/Media-Centre/Hot-Topics/Break-crop-research>

GRDC Fact Sheet 'Break crop benefits – Western': <http://grdc.com.au/Resources/Factsheets/2011/03/Break-Crop-Benefits-West>

GRDC Ground Cover supplement 'Flexible Farming': <http://gc-supplement.realviewdigital.com/?iid=66229&startpage=page0000015#folio=8>

GRDC RCSN Kwinana East-Planfarm Pty Ltd 'Break crop economics report': http://www.gga.org.au/files/files/1233_Planfarm_GRDC_RSCN_Breakcrop_Economics_2013_Final.pdf

DAFWA 'Break-crop benefits to wheat in WA': <http://www.publish.csiro.au/paper/CP11320.htm>

4.11.5 Cobalt (Co)

While not required by lupin plants, Cobalt is required by the rhizobia bacteria in root nodules.

Using seed with adequate concentrations of Co is sufficient to allow normal nodule development and N fixation in WA lupin crops.

Seeds with low Co concentrations sown into soils deficient in Co tend to produce poorly-nodulated lupin roots with ineffective nodules and the crop will be N deficient.

It is recommended to always use seed with Co levels higher than 0.13 mg/kg.⁶⁶

4.12 Nutrition benefits of lupin in the crop rotation

Incorporating lupin crops into WA crop rotations provides nutrition benefits to the whole farming system by increasing supply of organic/mineral N and reducing the need for N fertilisers.

WA lupin crops require high levels of N for normal growth and most of this comes from the atmosphere through symbiotic N fixation with rhizobia.

After the lupin crop is harvested, a significant proportion of this N remains behind in paddocks as decaying roots, fallen leaves and stubble. Over time, this source of N becomes available to subsequent crops.

Typically, the higher the lupin yield, the more organic/mineral N is left behind in the paddock because a high yielding crop has an abundance of roots, branches and leaves to support a large amount of grain.⁶⁷

Soil N must be converted to soluble organic compounds, such as amino acids, or an inorganic form, such as ammonium (NH₄⁺) or nitrate (NO₃⁻), to be available to subsequent crops as a plant available form of N.

This is carried out by soil microorganisms as these decompose soil organic matter, and/or residues from previous lupin crops (and other legumes and pastures).

Peak N demand from crops can be four or five times the rate of N mineralisation, but N fixation and residual N remaining after a lupin crop are highly valuable to the system.

Research has found that this source of N can substantially reduce the need for fertiliser N inputs – often by up to 40–80 kg N/ha in WA – and lift productivity of subsequent cereal and canola crops. On average, lupin crops across WA soils have been shown to fix about 130 kgN/ha.⁶⁸

4.12.1 Nitrogen budgets

The amount of N that will be fixed by a lupin (or other legume) crop and contribute to soil levels at the end of the growing season is determined by:

- » The amount of legume N accumulated over the growing season (measured in shoot dry matter (DM) production and percent N content)
- » The proportion of the legume N derived from atmospheric N₂ (often abbreviated as percent Ndfa).

Total N fixed by lupin is typically calculated by adjusting the shoot measures of N₂ fixation to include an estimate of how much fixed N might also be associated with the nodulated roots using a 'root factor'.⁶⁹

66 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

67 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

68 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

69 Peoples, M, Swan, T, Goward, L, Hunt, J, Hart, R, Hart, B (2015) Legume effects on available soil nitrogen and comparisons of estimates of the apparent mineralisation of legume nitrogen, CSIRO, Hart Bros Seeds, FarmLink Research, <http://www.agronomy2015.com.au/papers/agronomy2015final00161.pdf>

SECTION 4 LUPIN

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FEEDBACK

For many lupin and pulse legumes, about one third of the plant N may be below-ground in roots and nodules. In this case, a 'root factor' of 1.5 would be used. The equation is:

$$\text{Total N fixed} = (\text{shoot N fixed}) \times \text{root factor.}$$

Research indicates brown manured (BM) crops and forage legumes generally provide higher net returns of fixed N to soils than grain crops. This is because high amounts of N are removed in the high-protein legume grain at harvest.

However, researchers found it was also clear from these data that different legume species had different potential for growth and N₂ fixation regardless of eventual end-use.⁷⁰

As shown in Table 9, a trial in NSW showed concentrations of soil mineral N were 18 or 34 kg N/ha higher under a lupin grain crop-wheat and lupin BM-wheat sequences, respectively, than for wheat-wheat in 2013 when another wheat crop was grown.⁷¹

Table 9: Concentrations of soil mineral N (0-1.6m) measured in autumn 2012 and 2013 following either wheat, canola and lupin grown for grain or brown manure (BM) at Junee, NSW in 2011, and calculations of the apparent net mineralisation of N from lupin residues.⁷²

Crop grown in 2011	Soil mineral N autumn 2012 (kg N/ha)	Apparent mineralisation of legume N (% 2011 residue)	Soil mineral N autumn 2013 (kg N/ha)	Apparent net mineralisation of legume N (% 2011 residue)
Lupin BM	169	32%	167	12%
Lupin	119	22%	151	10%
Wheat	77	-	133	-
Canola	76	-	115	-
LSD (P<0.05)	35		20	

(SOURCE: CSIRO)

This research showed about 19 kg of legume shoot N is commonly fixed per tonne of shoot DM produced by pulse crops.

Median estimates of percent N derived from the atmosphere (Ndfa) across 35 growers' crops indicated these crops were deriving about 70 percent of N requirements from atmospheric N₂ and fixing about 6 kg shoot N/t DM produced.

The researchers concluded that residual fixed N from BM crops or pure pasture legume swards were generally higher than net inputs of fixed N remaining after pulses.

This was mostly due to the export of large amounts of N in harvested grain.

There is considerable evidence that the inclusion of legumes in cropping sequences results in higher available soil N for subsequent crops and this might be as much as 25-35 kg N/ha (on average) more mineral N than after wheat crops.⁷³

70 Peoples, M, Swan, T, Goward, L, Hunt, J, Hart, R, Hart, B (2015) Legume effects on available soil nitrogen and comparisons of estimates of the apparent mineralisation of legume nitrogen, CSIRO, Hart Bros Seeds, FarmLink Research, <http://www.agronomy2015.com.au/papers/agronomy2015final00161.pdf>

71 Peoples, M, Swan, T, Goward, L, Hunt, J, Hart, R, Hart, B (2015) Legume effects on available soil nitrogen and comparisons of estimates of the apparent mineralisation of legume nitrogen, CSIRO, Hart Bros Seeds, FarmLink Research, <http://www.agronomy2015.com.au/papers/agronomy2015final00161.pdf>

72 Peoples, M, Swan, T, Goward, L, Hunt, J, Hart, R, Hart, B (2015) Legume effects on available soil nitrogen and comparisons of estimates of the apparent mineralisation of legume nitrogen, CSIRO, Hart Bros Seeds, FarmLink Research, <http://www.agronomy2015.com.au/papers/agronomy2015final00161.pdf>

73 Peoples, M, Swan, T, Goward, L, Hunt, J, Hart, R, Hart, B (2015) Legume effects on available soil nitrogen and comparisons of estimates of the apparent mineralisation of legume nitrogen, CSIRO, Hart Bros Seeds, FarmLink Research, <http://www.agronomy2015.com.au/papers/agronomy2015final00161.pdf>

Other research in south-eastern Australia has indicated that a pulse grown for grain or BM can produce concentrations of available soil N that are 42–92 kg N/ha higher than those following wheat or canola in the first cropping season after the legume was grown. This represents apparent mineralisation of 20–30 percent of the N originally present in the legume residues.

In the second year, N concentrations were, on average, 18–34 kg N/ha, representing 10–12 percent of the residue legume N.⁷⁴

A general rule-of-thumb in WA is that doubling a legume grain yield doubles the N benefit to the next crop.

Management practices that can promote N fixation and high post-harvest residual N levels to achieve this in WA include:

- » Inoculate lupin seed with rhizobia before sowing to encourage high levels of nodulation
- » Aim for high yielding lupin crops
- » Choose the right variety for soil type and environment
- » Optimise nutrient inputs (especially P)
- » Apply lime to boost soil pH
- » Effectively manage weeds, diseases and pests
- » Use soil water conservation practices
- » Use reduced/zero-tillage to improve water infiltration
- » Sow on time and to meet optimal plant density targets.⁷⁵

4.13 Role of lupin in nutrient cycling

WA researchers are finding lupin can have an important role in nutrient cycling. This is driven by the plant's dominant and deep taproot being able to access nutrients, especially P and K, at depth and bring these closer to the surface.

This can increase nutrient availability to subsequent cereal crops, which tend to have a higher proportion of root systems in the shallower part of the soil profile.

Researchers carried out glasshouse trials in 2013 investigating narrow leafed lupin root traits that underpin efficient P acquisition.

Trials and simulation modelling showed lupin plants supplied with banded P had the biggest root system and highest P-uptake efficiency.

Addition of P significantly stimulated root branching in the topsoil, whereas plants with nil P had relatively deeper roots.

The researchers demonstrated that root hairs and root proliferation increased plant P acquisition and were more beneficial in the localised P fertilisation scenario.

They showed that placing P deeper in the soil might be a more effective fertilisation method, with greater P uptake, than using topdressing.

The combination of P foraging strategies (including root architecture, root hairs and root growth plasticity) was shown to be important for efficient P acquisition from a localised source of fertiliser.⁷⁶

The rooting depth of narrow leafed lupin tends to also allow plants to access K at depth in WA soils.

74 Peoples, M, Swan, T, Goward, L, Hunt, J, Li Guangdi Li, Harris, R, Ferrier, D, Browne, C, Craig, S, Van Rees, H, Mwendwa, J, Pratt, T, Turner F, Potter, T, Glover, A, Midwood, J (2015) Legume effects on soil N dynamics – comparisons of crop response to legume and fertiliser N, CSIRO, NSW DPI, Birchip Cropping Group, CropFacts, Central West Farming Systems, FarmLink, MacKillop Farm Management Group, Yeruga Crop Research, Riverine Plains Inc, Southern Farming Systems, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Legume-effects-on-soil-N-dynamics--comparisons-of-crop-response-to-legume-and-fertiliser-N>

75 GRDC (2014) Fact Sheet – Nitrogen fixation of crop legumes: basic principles and practical management, www.grdc.com.au/GRDC-FS-NFixation-Legumes

76 Chen, Y, Dunbabin, D, Postma, J, Diggle, A, Siddique, K, Rengel, Z (2013) Modelling root plasticity and response of narrow-leafed lupin to heterogeneous phosphorus supply, UWA, <http://research-repository.uwa.edu.au/en/publications/modelling-root-plasticity-and-response-of-narrowleafed-lupin-to-heterogeneous-phosphorus-supply/1dc591a6-de98-4083-a220-e17bda9e1381.html>

 **MORE INFORMATION**

DPIRD 'Effects of soil acidity': <https://www.agric.wa.gov.au/soil-acidity/effects-soil-acidity>

DAFWA 'Soil acidity – A guide for WA farmers and consultants': https://www.wheatbelt.nrm.org.au/sites/default/files/knowledge_hub/documents/Soil-acidity-farmers-guide-Bulletin-4784-for-screen.pdf

4.14 Lupin, nutrients and soil constraints

The dominant taproot of narrow leafed lupin plants can delve to a depth of up to 2.5 m, which is significantly deeper than the roots of field peas and barley – but this varies with variety and soil type.

In narrow leafed lupin, lateral roots branch out from the taproot and there is a higher proportion of root material below 20 cm in the soil than in wheat plants.

Albus lupin varieties have a more extensive lateral root system and are better adapted to shallower, finer-textured soils.

Typically, lupin root hairs have less resistance to water flow than cereal roots and the plant can take up more water and nutrients from deeper in the soil profile.

But root penetration can be limited on hard-setting soils and where subsurface hardpans exist, as roots tend to favor pathways with low levels of impediments.

There is global research that has shown some crop roots will explore soil cracks and pores, which may allow penetration of hardpans and access to underlying water and nutrients.

In WA, soil acidity (low pH) is a significant impediment to grain production and the major issue is Al toxicity in the subsurface.

For lupin, acidity in topsoils mainly affects nutrient availability and nodulation, most pronounced when pH is less than 5.5.

When subsurface pH falls below 4.8, this can affect crop root cell division and the ability of the root to penetrate to depth, branch out and access deep stored water and nutrients. This is most noticeable when there is a dry finish to the growing season.

Liming the topsoil and incorporating lime to depth using a range of soil amelioration tactics has been shown to be effective in boosting soil pH and reducing Al to non-toxic levels on WA soils.⁷⁷

⁷⁷ Gazey, C, Davies, S (2009) Soil Acidity – A guide for WA farmers and consultants, DAFWA, https://www.wheatbelt.nrm.org.au/sites/default/files/knowledge_hub/documents/Soil-acidity-farmers-guide-Bulletin-4784-for-screen.pdf

MORE INFORMATION

GRDC Hot Topic 'Lupin weed control': <https://grdc.com.au/Media-Centre/Hot-Topics/Lupin-weed-control>

GRDC 'Grain Legume Handbook, Chapter 5 Weed Control': <https://grdc.com.au/grainlegumehandbook>

GRDC Fact Sheet 'In-crop herbicide use': Use grdc.com.au/GRDC-FS-InCropHerbicideUse

GRDC 'Weed seedbank destruction' video: https://www.youtube.com/watch?v=6nTo_n47TxE#t=12

GRDC 'Weed ID: The Ute Guide' App: <https://grdc.com.au/apps>

GRDC Ground Cover Supplement 'Herbicide Resistance': <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS104>

WeedSmart: www.weedsmart.org.au

WeedSmart App: <https://grdc.com.au/apps>

DPIRD 'Crop weeds': <https://www.agric.wa.gov.au/pests-weeds-diseases/weeds/crop-weeds>

DPIRD 'Lupin diagnostic tool': <https://www.agric.wa.gov.au/pests-weeds-diseases/weeds/crop-weeds>

Weed management and herbicide use

5.1 Overview

Weed control in Western Australian lupin crops has long been a challenge due to poor crop competition and limited crop herbicide tolerance.

Research and experience in this State is finding integrated weed management (IWM) strategies that combine sustainable herbicide use/rotations coupled with lupin variety choice, time of sowing, improved crop competitiveness and harvest weed seed destruction can significantly reduce seedbanks of some weeds within three to five years.

Using a wide range of weed control tactics will also help suppress ongoing risks of herbicide resistance and facilitate long-term herbicide sustainability.

Major weeds that impact on lupin production in WA are:

- » Annual ryegrass (*Lolium rigidum*)
- » Wild oats (*Avena fatua* L.)
- » Brome grass (*Bromus diandrus* and *B. rigidus*)
- » Barley grass (*Hordeum*)
- » Wild radish (*Raphanus raphanistrum* L.).

Other weeds impacting on lupin productivity in this State include:

- » Capeweed (*Arctotheca calendula*)
- » Wild mustard (*Sisymbrium orientale*)
- » Doublegee (*Emex australis*)
- » A range of summer weeds.

Typically, it has been easier, more effective and cheaper to use selective herbicides to remove grassy weeds in lupin (and other broadleaf) crops and to control broadleaf weeds in cereal crops.

5.2 Herbicide types and use

The two types of herbicides are residual and non-residual. Residual types 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 isoxaflutole, imazapyr, chlorsulfuron, atrazine and simazine. The persistence of residual herbicides is determined by a range of factors. These include application rate, soil texture, organic matter levels, soil pH, rainfall and irrigation, temperature and the herbicide characteristics. The persistence of herbicides will affect the enterprise crop rotation.

Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

Herbicides are applied pre or post-emergent. Pre-emergent refers to application of the herbicide to the soil before weeds have emerged. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil.

A list of herbicide modes of action can be found here <https://www.croplife.org.au/resistance-strategy/2017-herbicide-mode-of-action-groups/>

The Australian Pesticides and Veterinary Medicines Authority (APVMA) has a complete list of registered herbicide products and actives at <https://apvma.gov.au/>

As highlighted in Table 1, including lupin in cereal rotations facilitates the use of herbicide modes-of-action (MOA)/actives that cannot be used in cereal phases to control grassy weeds and crop volunteers.

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Table 1: Registered herbicides for use in lupin¹. NOTE rates are per hectare.

	trifluralin	pendimethalin (e.g. Stomp)	triallate (e.g. Avadex)	simazine 50% flowable (on light soils) rates can be 2-3 L on gravelly-loams	simazine 50% + atrazine 50%	diuron 50% flowable	simazine 50% flowable top-up	diflufenican (e.g. Brodal)	diflufenican + metribuzin (750 g/kg and for some varieties)	picolinafen (e.g. Sniper)	metosulam (e.g. Eclipse)	tepraloxydim (e.g. Aramo)	sethoxydim	clethodim (e.g. Select) at 240 g/L	Butroxydim (Factor)	fluzafop (e.g. Fusilade)	haloxyfop 520g/L (e.g. Verdict with Uptake)
Group	D	D	J	C	C	C	C	F	F+C	F	B	A	A	A	A	A	A
Annual ryegrass	1.2-1.7 L	1.2-1.7 L		1.0-2.0 L (S)	0.5-1.0 L + 0.5-1.0 L (S)	2.0 L	0.75-2.0 L (S)					175-300 mL	0.5-1.0 L	150-500 mL	80-180 g	250 mL or 500 mL (weed size)	75 mL or 100 mL (weed size)
Brome grass				1.0-2.0 L (S)	0.5-1.0 L + 0.5-1.0 L (S)		0.75-2.0 L (S)					175-300 mL		175-500 mL		250 mL or 500 mL (weed size)	50 mL or 75 mL (weed size)
Barley grass				1.0-2.0 L (S)	0.5-1.0 L + 0.5-1.0 L (S)		0.75-2.0 L (S)					175-300 mL		175-500 mL	80-180 g	250 mL or 500 mL (weed size)	50 mL or 75 mL (weed size)
Silver grass				1.0-2.0 L	0.5-1.0 L + 0.5-1.0 L (S)		0.75-2.0 L										
Wild oat	1.2-1.7 L		1.6 L (Avadex Xtra at 500 g/L triallate)	1.0-2.0 L	0.5-1.0 L + 0.5-1.0 L (S)		0.75-2.0 L (S)					175-300 mL	0.5-1.0 L	175-500 mL	80-180 g	250 mL or 500 mL (weed size)	37.5 mL or 50 mL
Wild radish				1.0-2.0 L	0.5-1.0 L + 0.5-1.0 L	2.0 L	0.75-2.0 L	100-200 mL	100-150g + 100 mL	33-50g	50-70 mL						
Wild turnip				1.0-2.0 L	0.5-1.0 L + 0.5-1.0 L	2.0 L	0.75-2.0 L	100-200 mL									
Wild mustard				1.0-2.0 L	0.5-1.0 L + 0.5-1.0 L		0.75-2.0 L	100-200 mL									

S – suppression only

¹ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

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	trifluralin	pendimethalin (e.g. Stomp)	triallate (e.g. Avadex)	simazine 50% flowable (on light soils) rates can be 2-3 L on gravelly-loams	simazine 50% + atrazine 50%	diuron 50% flowable	simazine 50% flowable top-up	diflufenican (e.g. Brodal)	diflufenican + metribuzin (750 g/kg and for some varieties)	picolinafen (e.g. Sniper)	metosulam (e.g. Eclipse)	tepraloxymid (e.g. Aramo)	sethoxydim	clethodim (e.g. Select) at 240 g/L	Butroxydim (Factor)	fluzifop (e.g. Fusilade)	haloxyfop 520g/L (e.g. Verdict with Uptake)
Group	D	D	J	C	C	C	C	F	F+C	F	B	A	A	A	A	A	A
Doublegee				1.0-2.0 L	0.5-1.0 L + 0.5-1.0 L	2.0 L	0.75-2.0 L										
Capeweed				1.0-2.0 L	0.5-1.0 L + 0.5-1.0 L	2.0 L	0.75-2.0 L	200 mL (S)	100-150 and 100 mL (S)	50 mL (S)		50 mL and 100 mL Brodal (S)					
Wireweed	1.2-1.7 L	1.5-2.25 L (pre-plant incorp)			0.5-1.0 L + 0.5-1.0 L												

S – suppression only

(SOURCE: DPIRD/Protech Consulting)

MORE INFORMATION

Pulse Australia 'Lupin weed management': <http://www.pulseaus.com.au/growing-pulses/bmp/lupin#weed-management>

HerbiGuide: <http://www.herbiguide.com.au/>

Australian Glyphosate Sustainability Working Group: <http://www.glyphosateresistance.org.au/>

Adding lupin to the crop sequence also reduces carry over of inoculum from root and foliar diseases to provide a cereal disease break.

Effective IWM programs on individual properties will optimise opportunities to use selective herbicides in each crop phase of the rotation and reduce weed burdens for subsequent crops.

Without control of grass and broadleaf weeds, it has been estimated that yields in narrow leaved lupin crops can fall by as much as 65 percent. But there is significant reliance on six herbicide MOA in WA – as shown in Table 1 – and multiple herbicide resistance is a major issue for annual ryegrass and wild radish.²

Pre-emergent herbicides registered for use in WA lupin crops include:

- Simazine (Group C)
- Diuron (Group C)
- Atrazine (Group C)
- Triallate (Group J)
- Pendimethalin (Group D)
- Trifluralin (Group D).

Post-emergent herbicides registered for use in WA lupin crops include:

- Simazine
- Metribuzin (Group C)
- Diflufenican (Group F)

² White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cqi/viewcontent.cqi?article=1009&context=bulletins>

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- Metosulam (Group B)
- Haloxyfop (Group A)
- Clethodim (Group A).

For long-term, effective and sustainable weed control and herbicide efficacy, the key is to use a combination of herbicide, physical and cultural management tactics.

Newer narrow leaved lupin varieties, such as PBA Leeman[®], PBA Jurien[®], PBA Barlock[®] and Mandelup[®], have been shown to be higher yielding than older varieties under weed pressure and have better tolerance to some key herbicides, as illustrated in Table 2.

Table 2: Lupin variety response to herbicides in Western Australia 2005-2014.³

This research was conducted in the WA grainbelt (Eradu and Wongan Hills) to determine if new and existing varieties of narrow leaved lupin vary in tolerance to commonly used herbicides.

The sensitivity of the variety is summarised, using the following symbols based on the yield responses across all trials:

- N (w/z) narrow margin, significant yield reductions at higher than the label recommended rate, but not at the label recommended rate.
Significant event occurring in w trials out of z trials conducted. Eg (2/5) = tested in 5 trials, 2 trials returning a significant yield loss.
- x% (1/z) yield reduction (warning) significant yield reduction at recommended rate in 1 trial only out of z trials conducted.
- x-y% (w/z) yield reductions (warning) significant yield reductions at recommended rate in w trials out of z trials conducted.
- not tested or insufficient data
- ✓ no significant yield reductions at the label recommended rates in (z) trials.

Always follow label recommendations. The organisations involved in this research do not endorse the use of herbicides above the registered rate or off label use of herbicides or tank mixes. Any research with unregistered agricultural chemicals or of unregistered products reported in this GrowNote™ does not constitute a recommendation for that particular use by the author/s or the researcher/s organisation. All agricultural chemical applications must accord with the currently registered label for that particular pesticide, crop, pest and region. It must be emphasised that crop tolerance and yield responses to herbicides are strongly influenced by seasonal conditions.

Herbicides (Rates/ha)	Timing	Year of Testing	Coromop [®]	Jenebillup [®]	Mandelup [®]	PBA Barlock [®]	PBA Gunyidi [®]	PBA Jurien [®]	Pootallong [®]	Tanjil [®]
Year of Testing and Trial sites			2005-06, 12-14 AB	2006, 08 B	2005-06, 08-11 AB	2011-13 A	2009-12 A	2012-14 A	2005 A	2005-06 AB
Simazine 500 2 L (<i>simazine</i>)	Pre-seeding	2005-06, 08-14	N (2/5)	✓ (2)	N (2/6)	5 (1/3)	N (1/4)	N (1/3)	N (1/1)	N (1/2)
Diuron 500 2 L (<i>diuron</i>)	Pre-seeding	2008-14	10 (1/3)	✓ (1)	N (3/4)	N (3/3)	N (4/4)	N (2/3)		
Simazine 500 2.0 L + atrazine 500 1.0 L (<i>simazine + atrazine</i>)	Pre-seeding	2005-06,08	✓ (2)	✓ (2)	✓ (3)	-	-	-	✓ (1)	10 (1/2)
Simazine 2 L+ diuron 1 L + metribuzin 750 133 g (<i>simazine + diuron + metribuzin</i>)	Post-emergent	2005-06	✓ (2)	✓ (1)	✓ (2)	-	-	-	✓ (1)	✓ (2)

³ Dhammu, H, DAFWA research officer (2017), (08) 9690 2217, harmohinder.dhammu@agric.wa.gov.au

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Herbicides (Rates/ha)	Timing	Year of Testing	Coromop [®]	Jenebillup [®]	Mandelup [®]	PBA Barlock [®]	PBA Gunyidi [®]	PBA Jurien [®]	Pootallong [®]	Tanjil [®]
Year of Testing and Trial sites			2005-06, 12-14 AB	2006, 08 B	2005-06, 08-11 AB	2011-13 A	2009-12 A	2012-14 A	2005 A	2005-06 AB
Boxer Gold [®] 2.5 L (<i>S-metolachlor + prosulfocarb</i>)	Pre-seeding	2008-10,12	✓ (1)	✓ (1)	✓ (3)	✓ (1)	N (1/3)	5 (1/1)	-	-
Metribuzin 750 150 g (<i>metribuzin</i>)	Post-emergent	2008	-	✓ (1)	✓ (1)	-	-	-	-	-
Simazine 2 L + metribuzin 750 100-150 g plus 100 mL diflufenican (<i>simazine + metribuzin</i>)	Post-emergent	2012	✓ (1)	-	-	✓ (1)	✓ (1)	✓ (1)	-	-
Outlook [®] 1.0 L (<i>dimethenamid-P</i>)	Pre-seeding	2012-14	6 (1/3)	-	-	✓ (2)	✓ (1)	✓ (3)	-	-
Terbyne [®] 1.4 Kg (<i>terbuthylazine</i>)	Pre-seeding	2010-11	-	-	N (1/2)	✓ (1)	N (1/2)	-	-	-
Simazine 2 L fb Brodal [®] 200mL (<i>simazine fb diflufenican</i>)	Pre-seeding fb 2 leaves	2005-06,08-14	N (1/5)	✓ (2)	7 (1/6)	✓ (3)	8 (1/4)	N (1/3)	✓ (1)	✓ (2)
Simazine 2 L fb Sniper [®] 50 g (<i>simazine fb picolinafen</i>)	Pre-seeding fb 2 leaves	2005-06	✓ (2)	✓ (1)	✓ (2)	-	-	-	✓ (1)	✓ (2)
Simazine 2 L fb metribuzin 100-150 g plus 100 mL diflufenican (<i>simazine + metribuzin</i>)	Pre-seeding fb 2 leaves	2005-06, 08-14	7 (1/5)	N (1/2)	N (2/6)	N (1/3)	N (1/4)	✓ (3)	N (1/1)	12 (1/2)
Simazine 2 L fb Brodal [®] 100mL + Sniper [®] 33-50 g (<i>simazine fb diflufenican + picolinafen</i>)	Pre-seeding fb 4 leaves	2005-06	✓ (2)	✓ (1)	✓ (2)	-	-	-	✓ (1)	✓ (2)
Simazine 2 L fb Brodal [®] 100 mL + metribuzin 750 g (<i>simazine fb diflufenican + metribuzin</i>)	Pre-seeding fb 4 leaves	2005-06	✓ (2)	✓ (1)	✓ (2)	-	-	-	21 (1/1)	27 (1/2)
Simazine 2 L fb Brodal [®] 100 mL + metribuzin 750 150 g (<i>simazine fb diflufenican + metribuzin</i>)	Pre-seeding fb 4 leaves	2008-14	N (1/3)	✓ (1)	N (2/4)	N (1/3)	N (2/4)	N (2/3)	-	-
Simazine 2 L fb Sniper [®] 33-50 g + metribuzin 750 100 g (<i>simazine fb picolinafen + metribuzin</i>)	Pre-seeding fb 4 leaves	2005-06	✓ (2)	✓ (1)	✓ (2)	-	-	-	18 (1/1)	24 (1/2)
Simazine 2 L fb Brodal [®] 100 mL + Eclipse [®] 50 g (<i>simazine fb diflufenican + metosulam</i>)	From 8 leaf stage	2005-06, 08	✓ (3)	✓ (2)	✓ (3)	-	-	-	✓ (1)	✓ (2)
Simazine 2 L fb Sniper [®] 33-50 g + Eclipse [®] 50 g (<i>simazine fb picolinafen + metosulam</i>)	From 8 leaf stage	2005-06	✓ (2)	✓ (1)	✓ (3)	-	-	-	✓ (1)	✓ (2)
Simazine 2 L fb Brodal [®] 100 mL + simazine 0.75-1 L (<i>simazine fb diflufenican + simazine</i>)	Pre-seeding fb 4 leaves	2005-06, 08-14	11 (1/5)	✓ (2)	7-10 (2/6)	✓ (3)	6 (1/4)	10 (1/3)	✓ (1)	✓ (2)
Simazine 2 L fb Brodal [®] 100, 150, 200 mL + Sniper [®] 33-50 g + simazine 0.75-1 L (<i>simazine fb diflufenican + picolinafen + simazine</i>)	Pre-seeding fb 4 leaves	2005-06	✓ (2)	✓ (1)	✓ (2)	-	-	-	✓ (1)	9 (1/2)
Simazine 2 L fb Brodal [®] 100 mL + metribuzin 750 100 g + simazine 0.75-1 L (<i>simazine fb diflufenican + metribuzin + simazine</i>)	Pre-seeding fb 6 leaves	2005-06, 08	✓ (2)	✓ (2)	✓ (3)	-	-	-	30 (1/1)	25 (1/2)

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Herbicides (Rates/ha)	Timing	Year of Testing	Coromop [®]	Jenebillup [®]	Mandelup [®]	PBA Barlock [®]	PBA Gunyidi [®]	PBA Jurien [®]	Pootallong [®]	Tanjil [®]
Year of Testing and Trial sites			2005-06, 12-14 AB	2006, 08 B	2005-06, 08-11 AB	2011-13 A	2009-12 A	2012-14 A	2005 A	2005-06 AB
Simazine 2 L fb Sniper [®] 33-50 g + metribuzin 750 100 g + simazine 0.75-1 L (<i>simazine fb picolinafen + metribuzin + simazine</i>)	Pre-seeding fb 6 leaves	2005-06	✓ (2)	✓ (1)	✓ (2)	-	-	-	46 (1/1)	28 (1/2)
Simazine 2 L fb Brodal [®] 100 mL + Eclipse [®] 50 g (<i>simazine fb diflufenican + metosulam</i>)	From 8 leaf stage	2009-14	10 (1/3)	-	9 (1/3)	6-14 (2/3)	6-11 (2/4)	13 (1/3)	-	-
Simazine 2 L fb Eclipse [®] 50 g (<i>simazine fb metosulam</i>)	Pre-seeding fb 8 leaves	2009-14	12 (2/3)	-	N (1/3)	10 (1/3)	6-11 (2/4)	13 (1/3)	-	-
Eclipse [®] 7 g (<i>metosulam</i>)	From 8 leaf stage	2011	-	-	N (1/1)	N (1/1)	N (1/1)	-	-	-

The names in the parenthesis are the chemical names. fb = followed by. A= Eradu (Sandy to loamy sand, pH (CaCl₂): 4.2-6.2, OC: 0.45-1.05%, rainfall (May-Oct): 217 - 428 mm), B = Wongan Hills (Shallow duplex sandy to loamy sand, pH (CaCl₂): 4.6-4.9, OC: 0.7-0.9%, rainfall (May-Oct): 150-262 mm). Simazine, atrazine and diuron rates are based on their 500 formulations. Permit 14452 allows to use metribuzin 150 g a.i./ha pre-seeding in WA on Mandelup[®] and Coromup[®] varieties only. The permit is valid up to 30 June 2018. Higher than the label herbicide rates to work out crop safety margins (N) were not used for all the treatments.

Pootallong is a yellow lupin (*Lupinus luteus* L.) variety released during 2005.

A narrow crop safety margin implies that when spraying herbicide at the label rate under less than optimal conditions, herbicide damage and yield loss may occur. For example, when:

- overlapping herbicide
- spraying under wet conditions (for soil active and residual herbicides)
- there are stressed plants due to abiotic/biotic factors.

Research site location	Eradu (A)	Wongan Hills (B) 2006, 08
Site soil type	Eradu Sandplain	Loamy sand
Site pH (CaCl ₂)	5.5	4.6 - 4.9
Site annual average rainfall (mm)	374	

DISCLAIMER: While every care has been taken in preparing this publication, the organisations involved accept no responsibility for decisions or actions taken as a result of any data or interpretation contained in this report

NOTES to table: Safe use of herbicides on lupin⁴

- Interaction of mouldboard ploughing with shallow seeding and soil-applied residual herbicides in lupin could cause crop damage.
- High uptake of pre-emergent simazine and/or atrazine following good soil moisture or high usage rates may predispose the lupin crop to damage by typically 'safe rates' of post-emergent broadleaf herbicides. Symptoms may include leaf whitening, root rot or Brown leaf spot.
- Diflufenican (e.g. Brodal[®]) and picolinafen (e.g. Sniper[®]) alone, or in combination with other herbicides, cause bleaching/leaf spotting on most of the lupin varieties. Symptoms typically outgrow with time.
- The use of metribuzin alone, or in combination with other herbicides, may cause leaf burn and slight crop suppression in most varieties. Maximum rate of metribuzin 750 registered for post-emergent use on lupin is 150 grams ai/hectare.
- It is advised to not apply metribuzin in mixture with other herbicides if Brown leaf spot or other leaf diseases are present.
- Metosulam (e.g. Eclipse[®]) often causes yellowing, height and/or biomass reduction in most of the lupin varieties. Plants typically recover rapidly in typical

4 Dhammu, Harmohinder, DAFWA (2017), harmohinder.dhammu@agric.wa.gov.au

growing conditions. It is advised not to use oils and wetters with metosulam and to apply only on healthy crops up to the visible bud stage.

- Broadleaf herbicides should not be mixed with oil or products containing emulsifying agents.
- Application of broadleaf post-emergent herbicides to moisture-stressed lupin, or at the likely onset of moisture stress soon after application, can lead to damage from herbicides that are typically 'safe' when used in typical growing conditions.
- All grass selective herbicides at label rates are typically safe when used on lupin, but it is advised not to apply such products in a tank mix with the broadleaf herbicides – as crop damage will result.
- Ensure at least a 10-day break between spraying broadleaf herbicides and a grass selective herbicide.

WA experience has shown that the newest albus lupin variety, Amira[®], has good tolerance of registered herbicides and mixes at recommended rates.

Some research shows that it appears to have a low crop safety margin for pre-emergent simazine use and some post-emergent mixes with simazine.

MORE INFORMATION

Pulse Australia 'Residual Herbicides and Weed Control' hub: http://www.pulseaus.com.au/growing-pulses/publications/residual-herbicidesHerbiGuide_BoxerGold[®]: http://herbiguide.com.au/Descriptions/hg_Boxer_Gold.htm

HerbiGuide Sakura[®]: http://www.herbiguide.com.au/Descriptions/hg_Pyroxasulfone.htm

HerbiGuide Outlook[®]: http://www.herbiguide.com.au/Labels/DIMEP720_65695-63240.PDF

5.3 Managing residual herbicide issues

Lupin crops can be affected by herbicide residues where rainfall has been insufficient in both summer and the previous growing season.

Lupin has a particular sensitivity to Group B sulfonamide residues and, in high pH soils, some sulfosulfuron active residues can create problems.

All pulses, including lupin, are vulnerable to Group I phenoxy residues (such as 2,4-Damine and MCPA), particularly in sandy soils with low rates of microbial breakdown.

Clopyralid is another Group I active that has shown significant residual effects in lupincrops the following season after summer application in some areas.

The Group I chlorophenoxy herbicide Dicamba can also be an issue if it is used in autumn prior to sowing lupin crops in some areas.

Other Group I amide formulations tend to result in more residual issues than ester formulations in some regions and situations.

There may also be residue issues arising from the use of some newer herbicide options, such as the Group K metolachlor-prosulfocarb combination, Group C terbutylazine and Group K dimethenamid, as outlined below.

5.3.1 Tips for managing newer herbicide options

It is recommended, if using the Group K and Group E metolachlor and prosulfocarb Boxer Gold[®] herbicide as a pre-emergent, to apply to soil surface up to seven days before sowing lupin crops and incorporate it mechanically through the seeding process.

Application should be into a moist seedbed and when the outlook is for sufficient rain to thoroughly wet the top 3-4 cm of soil within 10 days of application.

It is advised to use Boxer Gold[®]:

- In seeding systems that ensure accurate seed placement and adequate separation of seed and herbicide
- Soils not prone to waterlogging
- When there are no heavy rains likely to cause run-off forecast within two days of application.

More information about this herbicide can be found at: http://herbiguide.com.au/Descriptions/hg_Boxer_Gold.htm

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If using the Group K pyroxasulfone herbicide, Sakura® 850 WG, it is best applied just before sowing and incorporated by the seeding process using knife points and press wheels (avoiding throwing treated soil into adjacent rows) or narrow points and harrows.

Note that Sakura® 850 WG can only be applied before sowing a lupin crop and lupin cannot be sown for nine months after this herbicide is used in situations such as a failed establishment of a wheat crop.

If using Sakura® 850 WG, it is advised to apply if:

- There is no heavy rain forecast within two days of application
- Incorporation with seeding can be achieved within three days of application
- Soil is not waterlogged.

It is advised not to use Sakura® where:

- Heavy rain has been forecast within 48 hours of application
- Incorporation by sowing (IBS) cannot be performed within three days of application
- There are waterlogged soils.

Other factors that may reduce weed control from Sakura® 850 WG include: uneven application; application to ridged or 'clodded' soils; high levels of stubble, plant residue or other ground cover; or if there is heavy rain on sandy soil types prone to leaching.

More information about Sakura® 850 WG is available at: http://www.herbiguide.com.au/Descriptions/hg_Pyroxasulfone

If considering the Group C herbicide terbuthylazine, apply to lupin as Terbyne® Xtreme® 875 WG, this is best used at the lower registered rate on lighter soils (such as sandy loams and loamy sands) and at higher registered rates on heavier soils (such as loams or silt-clay).

Best results will come from ensuring lupin seed is covered with 3-5 cm of soil at seeding and when there is sufficient rainfall (about 20-30 mm) within two or three weeks of application to wet the soil right through the weed root zone.

It is recommended to apply Terbyne® Xtreme®, if being considered for use in lupin crops, if there are no heavy rains forecast for two days, soils are not waterlogged and at rates less than 0.86 kilograms per hectare on soils with a pH of 8 or more.

The Group K herbicide dimethenamid-P, applied to lupin as Outlook®, controls annual ryegrass in low populations of typically less than 100 plants per square metre.

It will act to only suppress weeds in higher populations.

It is advised, if using, to apply this herbicide as late as possible before sowing and to use a knife point and press wheel system before weeds germinate. Weeds that are emerging, or emerge soon after application, are typically unlikely to be controlled, necessitating the use of a post-emergent knockdown.

i MORE INFORMATION

GRDC 'Integrated Weed Management Manual': www.grdc.com.au/IWMM

GRDC 'Integrated Weed Management': www.grdc.com.au/Resources/IWMhub/

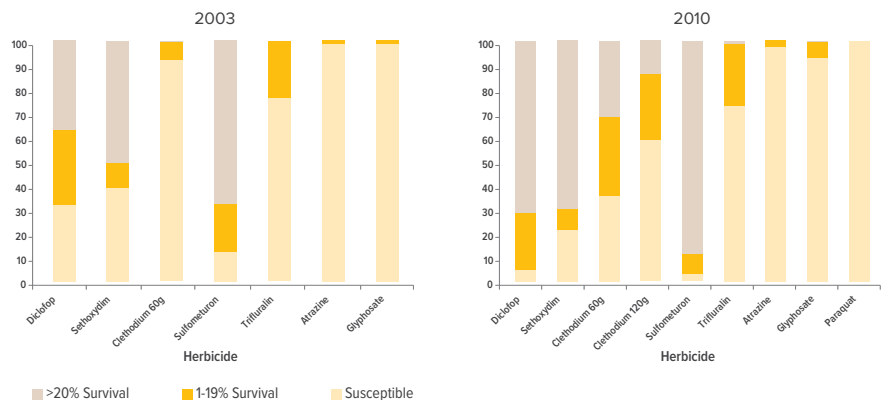
5.4 Importance of integrated weed management (IWM)

- Plan rotations in advance to minimise weed challenges
- Control weeds before or at sowing using physical, cultural and chemical methods
- Enable crops to compete strongly with weeds – using seeding rates, row spacing, nutrition
- Understand how to maximise herbicide efficacy
- Reduce seed set by weeds using crop-topping or desiccation
- Reduce the number of weed seeds in the paddock by using chaff carts, burning windrows left by headers, baling lupin straw or seed destruction/seeking technology.⁵

Adoption of IWM tactics is vital to sustaining long-term profitable cropping rotations in WA by achieving good weed control, helping to manage herbicide resistance and driving down weed seedbank numbers.

As shown in Figure 1, the incidence of annual ryegrass resistance to a range of herbicides in WA – as tracked through Australian Herbicide Resistance Initiative (AHRI) surveys – is high and increasing.

Figure 1: A snapshot of annual ryegrass resistance to a range of herbicides in WA, highlighting changes from 2003 to 2010 surveys.⁶



(SOURCE: AHRI)

Long-term WA 'Focus Paddock' trials – funded by the Grains Research and Development Corporation (GRDC) and carried out in conjunction with the Department of Primary Industries and Regional Development (DPIRD) – formerly the Department of Agriculture and Food Western Australia (DAFWA) – are demonstrating that it is possible to profitably crop at high intensity, while eroding the weed seedbank and in-crop weed numbers using an IWM approach. This is despite originally having high levels of herbicide resistance.⁷

In Focus Paddock trials from 2001 to 2013 in 31 central and northern grainbelt paddocks where IWM was used, annual ryegrass seedbank populations fell 96 percent from an average 183 annual ryegrass plants per square metre to only eight annual ryegrass plants/m². At the same time, an average cropping intensity of 89 percent was maintained.⁸

5 DPIRD (2016) Lupin Essentials – growing a successful lupin crop – weed control, https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C3#smartpaging_toc_p3_s0_h2

6 DPIRD (2015) Focus Paddock Report, GRDC website, <https://www.agric.wa.gov.au/grains-research-development/focus-paddocks-project-%E2%80%93-profitable-crop-and-pasture-sequencing>

7 DPIRD (2015) Focus Paddock Report, GRDC website, <https://www.agric.wa.gov.au/grains-research-development/focus-paddocks-project-%E2%80%93-profitable-crop-and-pasture-sequencing>

8 DPIRD (2015) Focus Paddock Report, GRDC website, <https://www.agric.wa.gov.au/grains-research-development/focus-paddocks-project-%E2%80%93-profitable-crop-and-pasture-sequencing>

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The Focus Paddock project highlighted the importance of harvest weed seed control (HWSC) in reducing weed populations as part of an IWM plan. It found growers who had the most success at managing annual ryegrass were those who practiced HWSC by towing a chaff cart and/or using narrow window burning. In the eighth year of using this practice, these growers had no annual ryegrass in their focus paddocks and have since averaged fewer than 1.5 ryegrass plants per square metre.⁹

WeedSmart, a GRDC and industry-funded herbicide sustainability initiative, has developed a 10 Point Plan for implementing IWM systems. This is available at the WeedSmart information hub (<http://www.weedsmart.org.au/10-point-plan/>) and outlines tips and tools for how to:

1. Act now to stop weed seed set
2. Capture weed seeds at harvest (HWSC)
3. Rotate crops and herbicide MOA
4. Test for resistance to establish a clear picture of paddock-by-paddock farm status
5. Aim for 100 percent weed control and monitor every spray event
6. Not automatically reach for glyphosate
7. Never cut the label herbicide rate, carefully manage spray drift and residues
8. Plant clean seed into clean paddocks with clean borders
9. Use the double-knock technique
10. Employ crop competitiveness to combat weeds.

DPIRD has produced a comprehensive IWM timeline for WA lupin crops, covering key weed control tactics and timing – from pre-sowing planning through to harvest. This can be seen in Table 3 and accessed online at this link <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>¹⁰

9 DPIRD (2015) Focus Paddock Report, GRDC website, <https://www.agric.wa.gov.au/grains-research-development/focus-paddocks-project-%E2%80%93-profitable-crop-and-pasture-sequencing>

10 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

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Table 3: Weed Management Time Line

Weed Management Time Line	
PRE-SOWING	
Paddock selection	Target a low weed burden paddock. Less than 20 to 30 ryegrass plants/m ² or less than 1 wild radish plant/m ²
Early herbicide application	Apply simazine on dry soil up to three weeks before sowing. Opening rains will incorporate simazine into the soil. Further incorporation by seeding after the break will ensure many weed seedlings will come in contact with the herbicide and be killed.
Variety selection	Use Mandelup [®] for improved competition against weeds except where the risk from anthracnose is high.
Seed quality	Check germination percentage to ensure good crop emergence. Germination can be reduced by crop-topping, storage and handling conditions, moisture content at harvest, seasonal growing conditions, seed size and insect damage.
Clean seed	Only sow clean seed—do not introduce weed problems.
CROP ESTABLISHMENT	
Dry sowing	Only dry sow lupin into a paddock that has a very low weed burden. Simazine requires moisture to be most effective. Weed control after dry sowing is likely to be variable.
Wet sowing	Wet sowing provides more even germination of weeds and lupin. Wet sowing allows simazine to work more effectively.
Target crop density	Aim for 45 plants/m ² to ensure the crop is competitive against weeds.
Row spacing – narrow row spacing (< 20 cm) – wide row spacing (> 20 cm)	Row spacing will influence crop competitiveness. Narrow rows ensure the crop is competitive against weeds due to higher plant densities. Use wide rows only if the paddock is very clean or shielded spraying is planned.
Pre-emergence weed control	If unsure of annual ryegrass numbers, use trifluralin. If using trifluralin in more than one cropping phase, consider resistance risk.
POST-EMERGENCE	
Insect pest management	Damage by Redlegged earth mites or Lucerne fleas can result in increased post-emergence herbicide uptake and damage to the crop. Damage by insects may make the crop less competitive.
POST-EMERGENCE BROAD-LEAFED WEED CONTROL	
2- to 6-leaf crop	Available options include simazine top-up; diflufenican (for example, Brodal [®] options); or picolinafen (Sniper [®]). Apply early as these options are most effective on small radish. Do not apply simazine to plants showing symptoms of simazine damage.
6-leaf crop	Use metribuzin in a mixture with diflufenican (for example, Brodal [®] options) on tolerant varieties. Mandelup [®] and Coromup [®] are the most tolerant varieties. Metribuzin is more effective on weeds and less damaging to the crop in the northern wheatbelt.
8-leaf to flower bud	Use metosulam (Eclipse [®]) for wild radish plants that have up to eight leaves or are about 20 cm in diameter. Wild radish that are resistant to Group B herbicides (for example, chlorsulfuron and triasulfuron) can also be resistant to metosulam.
POST-EMERGENCE GRASS WEED CONTROL	
Simazine top-up	Very limited benefit for grass weeds. Some late emerging or very small 1- to 2-leaf ryegrass may be controlled. Simazine has limited activity on larger grass weeds.

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Weed Management Time Line

Grass selective herbicides

Where herbicide resistance is not a problem, grass selective herbicides (Group A herbicides with a Fop or Dim chemistry) can be used.

The most effective grass weeds herbicides are often strong rates of Dim herbicides. However, be sure to know the resistance status of your weeds and choose the most effective chemical.

Lupin crops provide an important opportunity to manage brome grass with Group A grass selective herbicides.

Do not mix post-emergence grass selective herbicides with broad-leafed herbicides because crop damage will occur.

FLOWERING

No suitable selective weed control options

Herbicide application during flowering may result in flower loss and reduced yield.

Cut your losses

If weed numbers have exploded out of control this is the time to green or brown manure a failed lupin crop to maximise renovation benefits.

When brown manuring, use a double knockdown strategy to ensure that none of the weeds set seed.

LEAF DROP

50 percent leaf drop

Swathing will reduce seed set in ryegrass effectively, but will not control a high proportion of seed set in radish.

Yield losses can occur when picking up swaths. Swathed lupin should be harvested as soon as possible.

80 percent leaf drop

Crop-topping will reduce seed set in annual ryegrass, but often will not control a high proportion of seed set in radish.

Yield losses of 5 percent are common.

Do not keep seed from topped areas because viability may be reduced.

HARVEST

Timing

Harvest as early as possible before weed seeds fall to the ground.

Residue management

Catch or minimise spread of weed seed by using chaff carts or by concentrating residues in windrows (narrow header trails) for burning in autumn.

(SOURCE: DAFWA)

Crop competition and orientation are emerging as key non-herbicide weed control measures in WA and can be used in lupin crops to reduce weed burdens.

Research has shown that as crop density increases, crop biomass increases and weed growth and weed seed set fall due to crops out-shading and out-competing weeds for water and nutrients. The challenge is to achieve this in a practical and cost effective way.¹¹

¹¹ Borger, C (2015) East-west orientation for improved crop competition, DAFWA, <https://www.agric.wa.gov.au/grains-research-development/east-west-orientation-improved-crop-competition>

i MORE INFORMATION

GRDC Summer Fallow Weed Management Guide: www.grdc.com.au/GRDC-Manual-SummerFallowWeedManagement

GRDC Hot Topic ‘Summer fallow weed management’: www.grdc.com.au/Media-Centre/Hot-Topics/Summer-fallow-weed-management

5.5 Summer weed control



Figure 2: Summer weeds are a scourge of WA lupin crops.

(SOURCE: © Western Australian Agriculture Authority (Department of Agriculture and Food, WA))

- Conserves soil moisture and nutrients for crop use
- Reduces the need for high rates of herbicide knockdown before seeding
- Better controls large taproot species in knife point cultivation sowing systems
- Reduces risks of seeding delays
- Reduces weed allelopathic effects (such as toxin secretion) and can boost lupin emergence.¹²

The major summer weeds of WA cropping systems are:

- » Flaxleaf fleabane (*Conyza bonariensis*)
- » Windmill grass (*Chloris truncata*)
- » Caltrop (*Tribulus terrestris*)
- » Paddy melon (*Cucumis myriocarpus*)
- » Afghan melon (*Citrullus lanatus*).

Growth rates of these weeds after summer rain are high and control in early stages of development is typically more reliable and cost effective than waiting until they are more robust plants.

Simazine (Group C) can be applied for control of most summer grass and broadleaf weeds (except taproot species) in lupin crops in February/March with little loss up until May. Registered rates of simazine (600 grams per Litre) are 830 millilitres per hectare to 1.7 L/ha on light soils and 1.7-2.5 L/ha on gravelly-loam soils.¹³

Research and experience in parts of WA has found some weeds, such as fleabane, can only be adequately controlled in summer using a well-timed double-knock.

This is typically a full registered rate of glyphosate (Group M) followed by a full label rate of paraquat (Group L). But this adds pressure to spray all paddocks in a timely manner and increases weed control costs.

¹² White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

¹³ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

i MORE INFORMATION

GRDC update paper 'Managing clethodim resistant ryegrass': www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Herbicides-for-control-of-clethodim-resistant-annual-ryegrass

GRDC update Paper 'Why the obsession with the ryegrass seedbank': www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Why-the-obsession-with-the-ryegrass-seed-bank

HerbiGuide, Annual Ryegrass: http://www.herbiguide.com.au/Descriptions/hg_Annual_Ryegrass.htm

DPIRD 'Lupin weed control': www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop

Ryegrass Integrated Management (RIM) model: www.ahri.uwa.edu.au/RIM

Group B herbicides cannot be used for summer weed control on paddocks that will be sown to lupin due to the re-cropping interval. It is advised to always check the label before applying herbicides to lupin crops.

5.6 Grass weed control in lupin

5.6.1 Annual ryegrass (*Lolium rigidum*)



Figure 3: Annual ryegrass in a WA cereal crop.

(SOURCE: © Western Australian Agriculture Authority (Department of Agriculture and Food, WA))

- Highly competitive as early as two-leaf stage
- Can cause lupin yield losses of 5 percent for every 25 annual ryegrass plants/m²
- Late sown crops affected more by weed competition
- Can produce up to 45,000 seeds/plant in ideal conditions
- About 80 percent seed germination after season break
- Several waves of germination typically make control difficult
- Can carry crop root diseases between seasons and years
- Harvest costs may increase due to seed contamination
- Increasing levels of resistance to Group A and B herbicides in WA
- Multiple herbicide resistance to some selective/non-selective herbicides in WA
- The most documented glyphosate-resistant populations of all WA weeds
- Low resistance to atrazine (Group C) and trifluralin (Group D) in WA
- HWSC can be effective, as seed is retained at harvest height.^{14,15}

¹⁴ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

¹⁵ HerbiGuide website, Annual Ryegrass, http://www.herbiguide.com.au/Descriptions/hg_Annual_Ryegrass.htm

Management and control

Table 4: Tactics to consider when developing an integrated plan to manage annual ryegrass¹⁶

Annual ryegrass (<i>Lolium rigidum</i>)		Most likely % control (range)	Comments on use
Agronomy	Improve crop competition	50 (20–80)	Optimum sowing rates essential. Row spacing >250 mm to reduce crop competitiveness. Sow on time.
Tactic	Burning residues	50 (0–90)	Avoid grazing crop residues. Use a hot fire back-burning with a light wind.
Tactic	Inversion ploughing	95 (80–99)	Bury seed greater than 100 mm deep. Use of skimmers on the plough is essential for deep burial.
Tactic	Autumn tickle	15 (0–50)	Only effective on last year's seedset. Use in conjunction with delayed sowing.
Tactic	Fallow and pre-sowing cultivation	60 (0–90)	Cultivation may lead to increased annual ryegrass in the crop. Use in combination with a knockdown herbicide. Use cultivators that bury seed.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	80 (30–95)	Avoid overuse of the one herbicide MOA group. Wait until annual ryegrass has more than 2 leaves.
Tactic	Double knockdown or 'double-knock'	95 (80–99)	Reduces the likelihood of glyphosate resistance. Use glyphosate followed by paraquat or paraquat + diquat 3 to 10 days later.
Tactic	Pre-emergent herbicides	70 (50–90)	Note incorporation requirements for different products and planting systems.
Tactic	Selective post-emergent herbicides	90 (80–95)	Apply as early as possible after the annual ryegrass has 2 leaves to reduce yield losses in cereals.
Tactic	Spray-topping with selective herbicides	80 (60–90)	Apply before milk dough stage of annual ryegrass.
Tactic	Crop-topping with non-selective herbicides	70 (50–90)	Note stage of crop compared to stage of annual ryegrass. Often not possible to achieve without crop yield loss. Most likely to occur with quick finish to season.
Tactic	Pasture spray-topping	80 (30–99)	Graze heavily in spring to synchronise flowering.
Tactic	Silage and hay – crops and pastures	80 (50–95)	Most commonly used where there is a mass of resistant annual ryegrass growth. Follow up with herbicides or heavy grazing to control regrowth.
Tactic	Manuring, mulching and hay freezing	90 (70–95)	Most commonly used where there is a mass of resistant annual ryegrass growth. Follow up with herbicides or heavy grazing to control regrowth.
Tactic	Grazing – actively managing weeds in pastures	50 (20–80)	Graze heavily in autumn to reduce annual ryegrass plant numbers. Graze heavily in spring to reduce seedset.
Tactic	Weed seed collection at harvest	65 (40–80)	Best results when crop is harvested as soon as possible before ryegrass lodges or shatters.
Tactic	Sow weed-free seed	85 (50–99)	Reduces the risk of introducing resistant annual ryegrass to the paddock with crop seed.

(SOURCE: GRDC)

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Past research in WA has highlighted the importance of early weed control for annual ryegrass. The most effective double-knock interval between glyphosate and paraquat application has been found to be between two and 10 days for seedling annual ryegrass plants.¹⁷

At sowing, research has found increasing crop seeding rate and banding fertiliser below the lupin seed can improve lupin plant competition and help to reduce annual ryegrass establishment and seed set. A target plant density of 40-45 plants/m² is recommended for narrow leafed lupin crops to be competitive with annual ryegrass and to optimise yield potential, but this will vary widely between locations and seasons.

Using narrow row spacings (25 cm) has been found to improve weed control in lupin crops grown in WA's cooler, longer-season environments (such as the Lakes district and southern regions).¹⁸

Pre-emergent herbicides registered for use to control annual ryegrass in WA lupin crops are:

- Atrazine (Group A) – suppression only
- Simazine (Group C)
- Diuron (Group C)
- Trifluralin (Group D) – suppression only
- Pendimethalin (Group D)

Tips for pre-emergent herbicide applications in WA lupin crops include:

- » Label rate of simazine (600 g/kg) for WA lupin is 830 mL/ha to 1.7 mL/ha (light soil) and 1.7-2.5 mL/ha (loam soil)
- » Avoid simazine on deep white, grey/gritty sands
- » On yellow sandplain soils, crop damage from simazine formulation can occur at 1.25 L/ha
- » Trifluralin can be added if grass weeds are expected.
- » To manage resistance issues, try not to use trifluralin in multiple crops in the rotation.¹⁹

Post-emergent herbicides registered for use to control annual ryegrass in WA lupin crops are:

- Haloxyfop (Group A)
- Clethodim (Group A)
- Sethoxydim (Group A)
- Butroxydim (Group A)
- Diclofop (Group A)
- Fluazifop (Group A)
- Quizalofop (Group A)
- Propaquizafop (Group A)
- Paraquat (Group L.)

¹⁷ GRDC (2014) Integrated Weed Management Manual, GRDC Integrated Weed Management Manual: www.grdc.com.au/IWMM

¹⁸ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cqi/viewcontent.cgi?article=1009&context=bulletins>

¹⁹ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cqi/viewcontent.cgi?article=1009&context=bulletins>

Tips for post-emergent herbicide applications to control annual ryegrass in WA lupin crops include:

- » Spray small weeds early
- » Grass weeds need to be actively growing
- » Avoid spraying weeds stressed by dry soil, cold weather or frost
- » Use the highest registered label rate
- » Use the recommended adjuvant
- » Do not mix grass-selective and broadleaf herbicides
- » If applying paraquat during the season and/or to crop-top, use before weed seed set
- » Crop-topping with selective herbicides may be effective and economic
- » Test and monitor herbicide resistance status of annual ryegrass.²⁰

MORE INFORMATION

GRDC IWM hub 'Control of wild oats': <https://grdc.com.au/Resources/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping/Wild-oats>

GRDC Ute guide 'Wild oats': www.grdc.com.au/Resources/Ute-Guides/Weeds/Grass/West/Wild-oats

GRDC Podcast 'Controlling wild oats': <https://grdc.com.au/Media-Centre/GRDC-Podcasts/Southern-Weekly-Update/2015/10/103-south>

HerbiGuide, 'Wild Oats': www.herbiguide.com.au/Descriptions/hg_Wild_Oat.htm

5.6.2 Wild oats (*Avena sativa* ssp. *Fatua* and *A. ludoviciana*)



Figure 4: Group A resistant wild oats on the inter-row of wheat.

(SOURCE: GRDC)

- Highly competitive – as early as two-leaf stage
- Produce up to 20,000 seeds/m² if uncontrolled
- About 40 percent of seed germinates at season break
- Another 10-30 percent germinates later in the season
- Seedbank can be depleted by 75 percent per year with good control
- Minimum tillage, narrow row crop spacing and banded fertiliser boost crop competition
- Seed catching at harvest is only partially effective
- In early harvested crops, up to 75 percent of seed is typically captured
- In late harvested crops, very few seeds are caught
- Harvesters can spread seed up to 250 metres from the parent plant
- Burning windrows/paddocks pre-sowing can destroy seed on the soil surface and reduce seed dormancy
- Host for Cereal cyst nematode (*Heterodera avenae*) and the Root lesion nematode (RLN) *Pratylenchus neglectus*
- Poor host of the RLN *P. thornei*.^{21,22}

²⁰ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008. <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

²¹ GRDC (2014) Integrated Weed Management Manual, GRDC Integrated Weed Management Manual: www.grdc.com.au/IWM

²² HerbiGuide website, Wild Oats, http://www.herbiguide.com.au/Descriptions/hg_Wild_Oat.htm

Management and control of wild oats

Table 5: Tactics that should be considered when developing an integrated plan to manage wild oats²³

Wild oats (<i>Avena spp.</i>)		Most likely % control (range)	Comments on use
Agronomy	Crop choice and sequence	95 (30–99)	Summer crop–winter fallow rotation is very effective; numbers build up in winter pulse crops. Maintaining a clean winter fallow is the key to success.
Agronomy	Improve crop competition	70 (20–99)	Competitive crops at optimum sowing rates are very effective. High levels of control are achieved with barley, much lower with wheat.
Agronomy	Herbicide tolerant crops	90 (80–99)	Good to excellent control achieved with glyphosate resistant and triazine tolerant crops.
Tactic	Autumn tickle	40 (30–60)	Needs an break to season. Combine with delayed sowing.
Tactic	Delayed sowing	40 (30–60)	Must be used with an autumn ‘tickle’.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	80 (70–90)	Wait until youngest plants have 2 leaves if possible. Late germinations will not be controlled.
Tactic	Pre-emergent herbicides	80 (70–90)	Works best when combined with competitive crops
Tactic	Selective post-emergent herbicides	80 (70–90)	Test for resistance before spraying. Use in combination with competitive crops.
Tactic	Spray-topping with selective herbicides	90 (60–99)	Flamprop methyl is very effective on flamprop susceptible wild oats. Best results with competitive crops, warmer conditions and at very early jointing stage of wild oats. Group Z resistance is common in many areas.
Tactic	Pasture spray-topping	80 (70–90)	Graze or spray survivors. Hay freezing works well.
Tactic	Silage and hay – crops and pastures	97 (95–99)	Harvest when wild oats are flowering. Control regrowth.
Tactic	Grazing – actively managing weeds in pastures	75 (60–80)	Graze heavily and continuously in spring.
Tactic	Weed seed collection at harvest	70 (20–80)	Works well on early harvested crops before wild oats drop their seeds.
Tactic	Sow weed-free seed	95 (0–100)	Only sow seed produced in wild oat-free paddocks.
Tactic	Clean farm machinery and vehicles	80 (0–100)	Ensure harvesters are well cleaned before moving to clean property or paddock.

(SOURCE: GRDC)

It is advised to plant weed seed-free crop and pasture seed, use clean tillage and harvesting machinery and clean any imported hay/grain for livestock to keep paddocks clean.

Controlling wild oats early in the season will maximise lupin yields.

A knockdown herbicide, such as a full label rate of glyphosate, followed five to seven days later with a full label rate of paraquat and use of minimum tillage can set up lupin paddocks well.

Pre-emergent herbicides registered for use in wild oats in WA lupin crops are:

- Simazine (Group C) – registered for suppression only
- Atrazine (Group C) – registered for suppression only
- Triallate (Group J).

Post-emergent selective herbicides registered for use in wild oats in WA lupin crops are the Group A actives fluzafop-P and butoxydim.

Tips for post-emergent herbicide applications to help control wild oats in WA lupin crops include:

- » Apply top-up N before post-emergence spraying
- » Group A herbicides (Fops and Dims) usually provide best in-crop control
- » Repeated herbicide use may lead to resistance
- » Rotation with triallate + trifluralin can help delay resistance.²⁴

i MORE INFORMATION

DPIRD: <https://www.agric.wa.gov.au/grains-research-development/management-brome-grass-bromus-spp>

HerbiGuide, Brome grass: www.herbiGuide.com.au/Descriptions/hg_Great_Brome.htm

5.6.3 Brome Grass (*Bromus diandrus*; *B. diandrus rigidus* – previously known as *B. rigidus*)



Figure 5: An illustration of Fop and Dim resistant brome grass that has died-off when first sprayed, but recovered to produce new tillers.

(SOURCE: GRDC)

- Widespread across the WA grainbelt
- Highly competitive with crops
- More aggressive than annual ryegrass, barley grass or silver grass
- Tolerant to drought and phosphorus (P) deficiency
- Responds rapidly to N fertiliser applied in-crop
- Produces high numbers of seeds (600-3000 per plant)
- Host for nematodes and cereal diseases
- Declining use of some Group A and B herbicides in WA (as other weed species have developed widespread resistance)
- Confirmed resistance to sulfonyleureas (Group B) herbicides in six WA populations
- Resistance to Group A herbicides (Fops and Dims) in one population
- Resistance to glyphosate (Group M) confirmed in WA (a red brome population)
- Most seeds shed before harvest, so HWSC not highly effective.^{25,26}

24 GRDC (2014) Integrated Weed Management Manual, GRDC Integrated Weed Management Manual: www.grdc.com.au/IWMM

25 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

26 GRDC (2014) Integrated Weed Management Manual, GRDC Integrated Weed Management Manual: www.grdc.com.au/IWMM

Management and control of brome grass

Table 6: Tactics to consider when developing an integrated plan to manage brome grass²⁶

Brome grass (<i>Bromus</i> spp.)		Most likely % control (range)	Comments on use
Tactic	Burning residues	70 (60–80)	Sufficient crop residues are needed.
Tactic	Autumn tickle	50 (20–60)	Depends on seasonal break. Seed burial through shallow cultivation enhances seed depletion through germination, especially in <i>B. diandrus</i> with its shorter dormancy and faster germination.
Tactic	Delayed sowing	70 (30–90)	Best results with early seasonal break.
Tactic	Fallow	80 (70–90)	Start the chemical fallow before weeds set seed (i.e. early spring).
Tactic	Knockdown non-selective herbicides for fallow and pre-sowing control	80 (30–99)	If possible delay spraying until full emergence and youngest plants have 2 leaves.
Tactic	Pre-emergent herbicides	80 (40–90)	Follow label directions, especially on incorporation requirements of some herbicides.
Tactic	Selective post-emergent herbicides	90 (75–99)	Apply when weeds have 2 to 6 leaves and are actively growing.
Tactic	Pasture spray-topping	75 (50–90)	Spray before viable seedset. Respray or graze survivors. Use this technique 2 years before going back to crop.
Tactic	Silage and hay – crops and pastures	60 (40–80)	Silage is better than hay. Graze or spray regrowth.
Tactic	Manuring, mulching and hay-freezing	90 (75–95)	Manuring works well if done before seed set. Any regrowth must be controlled.
Tactic	Grazing – actively managing weeds in pastures	50 (20–80)	Graze infested areas heavily and continuously in winter and spring.
Tactic	Weed seed collection at harvest	70 (10–75)	Works best on early harvested crops before weeds drop their seeds

Lupin crops can provide a better opportunity to control brome grass than cereal crops, as there are more herbicide options available.

Preventing seed set later in the season with mowing, cultivation and/or burning windrows/paddocks can be effective in reducing the brome grass seedbank in the longer term.

Despite AHRI herbicide resistance surveys finding WA brome grass populations with resistance to some Group A, B and M herbicides, a range of pre and post-emergent options are still available to control this weed.

Crop-topping with glyphosate in lupin crops may also reduce brome grass seed set. Timing is the main issue to consider, as brome grass matures a lot faster than some crops and will set seed before the crop can be legally sprayed.

Lupin crops typically mature early enough to kill many grass weeds by crop-topping, but this will require using an early maturing crop variety and sowing early.²⁷

The Group C pre-emergent herbicides simazine and atrazine are registered for suppression of brome grass in WA lupin crops.

²⁷ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

i MORE INFORMATION

DPIRD 'Barley grass': <https://www.agric.wa.gov.au/grains-research-development/barley-grass>

HerbiGuide, 'Barley Grass': http://www.herbiguide.com.au/Descriptions/hg_Barley_Grass.htm

Post-emergent herbicides registered to help control brome grass in WA lupin are:

- Clethodim (Group A)
- Butoxydim (Group A)
- Fluazifop (Group A)
- Haloxyfop (Group A)
- Quizalofop (Group A)
- Propaquizafop (Group A).

5.6.4 Barley grass (*Hordeum glaucum* and *H. leporinum*).



Figure 6: Barley grass can be a source of stripe rust disease in grain cropping and pasture areas of WA.

(SOURCE: GRDC)

- Germinates rapidly in autumn
- Group A herbicides typically provide good control in lupin
- Some WA populations have resistance to Group B (SU) herbicides (such as sulfometuron and sulfosulfuron)
- Other states have barley grass with resistance to paraquat and diquat; several Group A Fops; and cross resistance to the Group A Dim herbicides.²⁸

28 DPIRD (2016) Barley Grass, <https://www.agric.wa.gov.au/grains-research-development/barley-grass>

Management and control of barley grass

Table 7: Tactics to consider when developing an integrated plan to manage barley grass²⁹

Barley grass (<i>Hordeum</i> spp.)		Most likely % control (range)	Comments on use
Agromony	Crop choice and sequence	85 (0-95)	Avoid planting barley in infested areas.
Agromony	Herbicide tolerant crops	80 (40-95)	Triazines and imidazolinone herbicides provide useful control in triazine and imidazolinone tolerant crops respectively.
Tactic	Burning residues	50 (0-75)	Dropping chaff and straw into windrows improves control.
Tactic	Inversion ploughing	90 (70-99)	Use skimmers to ensure deep burial.
Tactic	Delayed sowing	60 (50-90)	Level of control depends on break.
Tactic	Fallow and pre-sowing cultivation	50 (30-80)	Requires dry weather following cultivation.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	80 (50-90)	Works best if delayed until the 2- to 4-leaf stage after good opening rains.
Tactic	Double knockdown or 'double-knock'	80 (60-95)	Works best if delayed until the 2- to 4-leaf stage after good opening rains.
Tactic	Pre-emergent herbicides	85 (75-99)	Pyroxasulfone provides good control in wheat.
Tactic	Selective post-emergent herbicides	90 (80-95)	Several Fop herbicides provide good control in broadleaf crops. Sulfosulfuron provides suppression in wheat.
Tactic	Crop-topping with non-selective herbicide	80 (50-90)	Timing is aimed at maximising weed seed kill and minimising effect on the crop.
Tactic	Pasture spray-topping	60 (50-90)	Graze heavily or winter-clean with Fop herbicides to induce more uniform emergence of heads. Timing is critical. Graze or spray regrowth.
Tactic	Silage and hay – crops and pastures	50 (30-80)	Silage provides better control than hay making. Heavily graze or spray regrowth.
Tactic	Manuring – green and brown, mulching and hay freezing	75 (50-90)	Graze heavily to induce more uniform emergence of heads. Timing is critical. Graze or spray regrowth.
Tactic	Grazing – actively managing weeds in pastures	30 (0-50)	Use high stocking rates early in the season to reduce numbers, and late in the season to reduce seedset on infested paddocks.

(SOURCE: GRDC)

Simazine and atrazine (Group C actives) are pre-emergent herbicide options to help control barley grass in WA lupin crops, although atrazine is registered for suppression only.

Post-emergent herbicide options to help control barley grass in WA lupin are:

- Clethodim (Group A)
- Butroxydim (Group A)
- Fluazifop (Group A)
- Haloxyfop (Group A)
- Quizalofop (Group A)
- Propaquizafop (Group A).

i MORE INFORMATION

DPIRD 'Silver grass' hub: <https://www.agric.wa.gov.au/grains-research-development/silver-grass?page=0%2C1>

5.6.5 Silver grass (*Vulpia myuros* and *V. bromoides*)



Figure 7: Silver grass can reduce lupin crop yields when at high densities.

(SOURCE: Agronomo)

- Can severely reduce crop yields when at high densities
- A host for diseases and pests, including cereal root diseases, webworm and some RLNs
- No confirmed cases of herbicide resistant silver grass in WA
- There are cases of paraquat resistance in other states
- Many herbicides provide suppression, rather than control, of silver grass
- Some herbicides only control surface-germinating seeds (always check the herbicide label)
- Seed has little dormancy, making early control of the initial flush of germination highly effective.³⁰

30 DPIRD (2016) Silver Grass, <https://www.agric.wa.gov.au/grains-research-development/silver-grass>

Management and control of silver grass

Table 8: Tactics to consider when developing an integrated plan to manage silver grass³¹

Silver grass (<i>Vulpia</i> spp.)		Most likely % control (range)	Comments on use
Agronomy	Crop choice and sequence	80 (70–95)	Rotate to a triazine tolerant or glyphosate resistant canola in heavily infested areas.
Agronomy	Herbicide tolerant crops	95 (90–99)	Using pre- and post-emergent applications of triazine herbicide in triazine tolerant crops will almost eradicate most species of <i>Vulpia</i> .
Agronomy	Improve pasture competition	Variable	Reduces seed production, helping to maintain a low incidence of silver grass in a pasture. Winter clean with simazine.
Tactic	Burning residues	50 (30–70)	Use a hot fire back-burning into the wind.
Tactic	Inversion ploughing	90 (80–99)	Use a plough with skimmers to bury seed more than 75 mm deep.
Tactic	Autumn tickle	60 (50–80)	Requires an early break to the season. Combine with delayed sowing.
Tactic	Delayed sowing	75 (50–90)	Works well in most seasons. Tends to fail on non-wetting soils.
Tactic	Fallow and pre-sowing cultivation	70 (50–90)	Generally works well. Crop using full soil disturbance with late sowing to enable use of knockdown herbicides plus cultivation.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	Up to 95%	Ensure good herbicide coverage.
Tactic	Double knockdown or 'double-knock'	80 (70–95)	If this is required, pasture cleaning or spray-topping should have occurred 2 years before cropping.
Tactic	Pre-emergent herbicides	80 (70–95)	Triazines are very good on most species of <i>Vulpia</i> .
Tactic	Selective post-emergent herbicides	Up to 95%	If silver grass is the main component of the pasture there will be a loss of winter fodder. The treated pasture should be resown in the following season or renovated to increase the component of desirable species.
Tactic	Pasture spray-topping	Up to 85%	Timing is critical. Heavy grazing leading up to topping will induce uniform head emergence. Gives the ability to keep desirable pasture species while reducing the incidence of silver grass. Conduct two seasons before cropping.
Tactic	Silage and hay – crops and pastures	Up to 90%	Cut for silage at commencement of flowering. Control regrowth.
Tactic	On-farm hygiene	Variable	Contaminated hay should not be moved to clean areas.

(SOURCE: GRDC)

Simazine is the registered pre and post-emergent herbicide option for control of silver grass in WA lupin crops. The other Group C active, atrazine, can be used for suppression in lupin.

31 GRDC (2014) Integrated Weed Management Manual, GRDC Integrated Weed Management Manual: www.grdc.com.au/IWMM

i MORE INFORMATION

GRDC Fact Sheet 'Wild radish': www.grdc.com.au/GRDC-FS-WildRadishManagement

GRDC Hot Topic 'Wild radish control options in WA': www.grdc.com.au/Media-Centre/Hot-Topics/Wild-radish-control-options-in-WA

GRDC 'Herbicide resistance testing': www.grdc.com.au/Media-Centre/Media-News/South/2014/04/Herbicide-resistance-testing-autumn-2014

DPIRD 'Wild radish': <https://www.agric.wa.gov.au/grains-research-development/wild-radish>

5.7 Broadleaf weed control in lupin

5.7.1 Wild radish (*Raphanus raphanistrum*)



Figure 8: Wild radish is one of the most widespread weeds in WA and can cause losses in lupin yields through competition.

(SOURCE: GRDC)

- One of the most widespread and competitive broadleaf weeds in Australia
- Can cause yield losses of 10-90 percent in WA lupin crops
- A prolific seeder with high seedbank dormancy
- Up to 70 percent of seeds still dormant in the next cropping season
- More than 90 percent of populations in WA resistant to one or multiple herbicides
- High resistance to some Group B and Group I herbicides (sulfonylureas, sulfonamides and phenoxy)
- Populations with resistance to some Group F and C herbicides
- Resistance to glyphosate found in WA in 2013
- Triazines still effective in the majority of WA paddocks, but resistance becoming widespread
- Important to kill in-crop weeds while small – less than 20 cm diameter
- Seeds become viable within three weeks of first flowers
- Retains seed pods at harvest height, making HWSC effective
- Long-term management requires driving seed numbers down to low levels
- Hand picking of resistant plants in-crop is being evaluated in parts of WA.^{32,33}

³² DPIRD (2016) Wild Radish, <https://www.agric.wa.gov.au/grains-research-development/wild-radish>

³³ GRDC (2014) Fact Sheet – Wild radish, www.grdc.com.au/GRDC-FS-WildRadishManagement

Management and control of wild radish

Table 9: Tactics to consider when developing an integrated plan to manage wild radish³⁴

Wild radish (<i>Raphanus raphanistrum</i>)		Most likely % control (range)	Comments on use
Agromony	Herbicide tolerant crops	90 (80–99)	If growing canola in a crop sequence with lupin in a wild radish infested area it is essential to use a herbicide resistant variety and associated herbicide package.
Tactic	Burning residues	70 (20–90)	In concentrated windrows. Burn when conditions are conducive to a hot burn.
Tactic	Inversion ploughing	98 (20-100)	Plough must be correctly 'set up' and used under the right conditions. Must use skimmers.
Tactic	Autumn tickle	45 (15–65)	Follow-up rain is needed for better response.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	80 (70–90)	Add a reliable herbicide spike for more reliable control. Late germinations will not be controlled.
Tactic	Selective post-emergent herbicides	90 (70–99)	Apply to young and actively growing weeds. Repeat if necessary to control late emerging weeds or survivors.
Tactic	Spray-topping with selective herbicides	80 (70–95)	Wild radish may regrow if there are late rains. Good for seedset control. Spray before embryo development for best results.
Tactic	Wiper technology	70 (50–80)	Has potential in low growing pulses such as lentils.
Tactic	Silage and hay – crops and pastures	80 (70–95)	Cut before embryo formation in developing wild radish seed (21 days after first flower). Graze or spray regrowth.
Tactic	Manuring, mulching and hay freezing	95 (90–100)	Brown manuring more efficient than green manuring and more profitable. Grazing before spraying to open sward will improve results. Hay freezing works well and is the most profitable manuring option in most cases.
Tactic	Grazing – actively managing weeds in pastures	70 (50–80)	Rotationally graze and use spray-grazing. Can also use slashing to improve palatability and reduce pasture growth rate in spring.
Tactic	Weed seed collection at harvest	75 (65–85)	Most reliable in early harvested paddocks.
Tactic	Sow weed-free seed	95 (90-100)	Very important as resistance in wild radish is increasing and introduction via crop seed is increasingly likely.

(SOURCE: GRDC)

34 GRDC (2014) Integrated Weed Management Manual, GRDC Integrated Weed Management Manual: www.grdc.com.au/IWMM

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High seed dormancy and increasing levels of herbicide resistance make wild radish difficult to control in WA lupin crops, which are also poor competitors with this weed.

Lowering the wild radish seedbank can take up to 10 years, as any plants that survive one season to set seed will replenish the soil with a new wave of dormant seed that can take up to 18 months to germinate.³⁵

Effective control of this weed requires an integrated approach involving:

- » Testing seed from surviving wild radish plants at harvest for herbicide resistance
- » Application of glyphosate and/or paraquat during summer at full label rates
- » Narrow row spacing or paired rows at seeding to boost crop competition
- » Harvest weed seed capture and destruction
- » Weed detection technology, if cost effective
- » Use of decision-support tools, such as Weed Seed Wizard.³⁶

In recent years, there has been a sharp increase in levels of wild radish resistance to commonly used herbicides for control of this weed in WA.

The 2010 AHRI herbicide resistance surveys for wild radish in WA found:

- » 84 percent contained plants resistant to chlorsulfuron (Group B) – up 30 percent from 2003 levels.
- » 49 percent were resistant to Intervix (Group B)
- » 76 percent were resistant to 2,4-D amine
- » 49 percent were resistant to Brodal® (Group F)
- » One population had atrazine resistant plants.³⁷

Wild radish control in WA is heavily dependent on the use of simazine (Group C) pre-emergent herbicides, with a post-emergent mix of diflufenican (Group F) and metribuzin.

Key challenges for growers have been wild radish populations with multiple resistance to simazine and diflufenican, which has reduced the effectiveness of these herbicides.

Wild radish with resistance to sulfonylureas (Group B) herbicides has also become widespread.³⁸

The release of lupin varieties PBA Leeman[®], PBA Jurien[®] in 2016 and PBA Barlock[®] in 2013 are seen as positive steps in improving control of weeds for the WA lupin industry.

These varieties have enhanced tolerance of the herbicide metribuzin (higher than Tanjil[®] and equal to PBA Mandelup[®]) and resistance to the disease anthracnose.

Triazine herbicides (Group C – including simazine and atrazine) remain highly effective in controlling wild radish in lupin crops.

To maximise effectiveness and longevity of these herbicide MOAs, it is advisable to sow crops when the soil is wet after the break and use varieties with good triazine tolerance, such as PBA Leeman[®], PBA Jurien[®], PBA Barlock[®], Mandelup[®] and PBA Gunyidi[®].

Research in WA's northern agricultural region in 2012-13 found a two-spray strategy for wild radish increased lupin yields by 0.4-0.5 t/ha on average – and up to 1 t/ha at some sites – compared to untreated weeds. The first treatment was a full label rate of a Group C or F herbicide at the weed two-leaf stage (less than 20 cm in diameter),

35 GRDC (2014) Fact Sheet – Wild radish, www.grdc.com.au/GRDC-FS-WildRadishManagement

36 DPIRD (2016) Wild Radish, <https://www.agric.wa.gov.au/grains-research-development/wild-radish>

37 Australian Herbicide Resistance Initiative (2015) Wild Radish Surveys, The University of Western Australia, <http://ahri.uwa.edu.au/research/surveys/wild-radish/>

38 Australian Herbicide Resistance Initiative (2015) Wild Radish Surveys, The University of Western Australia, <http://ahri.uwa.edu.au/research/surveys/wild-radish/>

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followed by a second full rate application of an alternative herbicide MOA at the weed five-leaf stage.³⁹

Research trials have shown for every one wild radish plant/m², lupin yields fall by an average of 5 percent in most WA grainbelt areas.⁴⁰

Wild radish reduces lupin yields by decreasing pod number, grain size and germination rates.

Increasing lupin crop density to a target of 50 plants/m² has been found to reduce the adverse yield effects of this weed.⁴¹

WA research has demonstrated that increased lupin crop density and competition with wild radish can be achieved by a combination of:

- » High seeding rates of about 100 kg/ha
- » Narrow row spacing of 17-25 cm
- » Paired row spacing of 7.5 cm
- » Using east-west sowing row orientation.⁴²

Existing machinery can be modified for paired-row seeding so that the tyne spacing best for stubble handling and sowing speed can stay the same.

Growers in WA's northern agricultural area, in particular, have been able to drive wild radish seedbank numbers to very low levels using a range of these mechanical, cultural and herbicide IWM tactics.

Researchers in this region are now investigating the cost effectiveness and thresholds for hand-picking surviving wild radish plants in-crop to further reduce weed burdens.

For herbicide control of wild radish, pre-emergent options registered for use in WA lupin crops are:

- Simazine (Group C)
- Atrazine (Group C)
- Diuron (Group C).

Wild radish is not highly damaging to yield potential early in the season.

Simazine followed by a top-up application two to five weeks after planting usually provides good control.

Post-emergent herbicides registered to control wild radish in WA lupin crops are:

- Metosulam (Group B)
- Simazine (Group C)
- Metribuzin (Group C)
- Diflufenican (Group F)
- Picolinafen (Group F).

Tips for post-emergent herbicide use for wild radish in WA lupin crops include:

- » Use full label rates
- » Diflufenican can be used for early control – it is unlikely to kill large weeds
- » Metribuzin can cause crop damage to some varieties, exacerbated in colder climates
- » Varieties Gunyidi[®], PBA Leeman[®] and PBA Barlock[®] are more tolerant of metribuzin
- » Mixing broadleaf and grass herbicides will damage lupin and should be avoided.⁴³

39 Newman, P (2013) We can kill wild radish in lupins if we have enough spray capacity, GRDC DAFWA 2013 Agribusiness Crop Updates paper, www.giwa.org.au/past-crop-updates

40 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

41 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

42 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

43 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

5.7.2 Wild mustard/Indian hedge mustard (*Sisymbrium orientale*)



Figure 9: Wild mustard is a prolific seed producer but is not a big problem for WA lupin crops

- Produces vast numbers of seeds (up to 30,000/m²)
- Causes problems at harvest
- Small seeds can cause grain contamination.
- Not a major weed of WA lupin crops.⁴⁴

Management and control

Table 10: Tactics that should be considered when developing an integrated plan to manage Indian hedge mustard⁴⁵

Indian hedge mustard (<i>Sisymbrium orientale</i>)		Most likely % control (range)	Comments on use
Agronomy	Crop choice and sequence	85 (0-99)	Avoid crops with no post-emergent herbicide options.
Agronomy	Herbicide tolerant crops	80 (0-95)	Very useful for non-cereal portions of the rotation.
Tactic	Autumn tickle	25 (10–50)	Use with early breaks to the season and combine with delayed sowing.
Tactic	Delayed sowing	95 (90–99)	Follow by knockdown with non-selective herbicides targeting small weeds.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	75 (50–80)	Use high rates to control biennial plants. Tank-mixing with phenoxy herbicides improves control in absence of Group I resistance. Late germinations are not controlled.
Tactic	Pre-emergent herbicides	75 (50–80)	Dry conditions post-sowing reduces herbicide efficacy.
Tactic	Selective post-emergent herbicides	80 (60–90)	Spray young actively growing plants and repeat if necessary. Be aware of resistance status.
Tactic	Spray-topping with selective herbicides	95 (85–99)	Be aware of resistance status. The control range assumes no Group B resistance.
Tactic	Wiper technology	80 (60–95)	Useful tactic in lentils.
Tactic	Grazing – actively managing weeds in pastures	70 (50–80)	Rotationally graze. Use spray-grazing with herbicide suited to pasture species present.
Tactic	Weed seed collection at harvest	50 (10–70)	Useful on early harvested crops.

(SOURCE: GRDC)

44 HerbiGuide, Wild Mustard, http://www.herbiGuide.com.au/Descriptions/hg_Indian_Hedge_Mustard.htm

45 GRDC (2014) Integrated Weed Management Manual, GRDC Integrated Weed Management Manual: www.grdc.com.au/IWMM

Wild mustard is found in the WA grainbelt, but is not a major weed of economic importance for growing lupin crops. The pre-emergent herbicide options for control are simazine (Group C) and atrazine (Group C).

Post-emergent herbicide options to control wild mustard in WA lupin crops are simazine and diflufenican (Group F).

5.7.3 Wireweed (*Polygonum aviculare*, *P. arenastrum*)



Figure 10: Wireweed is a prolific seed producer but is not a big problem for WA lupin crops

(SOURCE: Agronomo)

- Autumn to early summer germinating, annual or biennial
- Delayed germination makes control difficult
- Competes for moisture and nutrients
- Often causes problems with machinery
- Has phytotoxic properties.⁴⁶

Management and control

Table 11: Tactics to consider when developing an integrated plan to manage wireweed.⁴⁷

Wireweed (<i>Polygonum</i> spp.)		Most likely % control (range)	Comments on use
Agronomy	Crop choice and sequence	80 (0–50)	Avoid continuous cereals or broadleaf crops where control is difficult. Avoid growing pulses in heavily infested paddocks. Wireweed increases in triazine tolerant canola.
Agronomy	Herbicide tolerant crops	90 (50–95)	Some imidazoline herbicides provide useful control in legume and imidazoline tolerant crops. Glyphosate will provide good control in glyphosate tolerant crops.
Agronomy	Fallow phase	80 (0–80)	Control early in the fallow to reduce vining (i.e. kill small plants).
Tactic	Inversion ploughing	90 (80–95)	Use once to bury resistant seed deeply then avoid bringing that seed back to the surface for at least 10 years.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	90 (75–90)	Glyphosate, dicamba and some sulfonylurea herbicides are the most effective.
Tactic	Pre-emergent herbicides	90 (50–80)	Trifluralin, pendimethalin, chlorsulfuron and triasulfuron provide good control, but are dependent on rain after application.
Tactic	Selective post-emergent herbicides	90 (75–90)	Metsulfuron and dicamba provide good control. Target small weeds for better control. Few options exist in broadleaf crops.
Tactic	Manuring, mulching and hay freezing	90 (50–80)	Good for controlling late germinations and reducing problems in summer fallow.

(SOURCE: GRDC)

Wireweed tends to germinate during or after crop emergence and competes for soil moisture and nutrients.

Typically, it does not affect lupin yields significantly, but it can cause problems in blocking sowing equipment and/or interfere with harvesting due to its lengthy branching.

It can affect rhizobia bacteria required for lupin nodulation due to its phytotoxic properties and it is tolerant of atrazine.⁴⁸

Pre-emergent herbicide options for control of wireweed in WA lupin crops include:

- Trifluralin (Group D)
- Pendimethalin (Group D)
- Atrazine (Group C).

5.8 Crop-topping for weed control

- Apply a non-selective herbicide (paraquat, Group L) prior to harvest
- Always check label for registration, rate and timing details
- Time application to target weeds at flowering and early grain fill
- This will minimise production of viable weed seed and crop yield loss
- Success requires sufficient gap in physiological maturity between crop and weed
- Ideal time is when 80 percent of lupin leaves have turned brown or fallen off
- Works best with early maturing lupin varieties.⁴⁹

Management when crop-topping

Paraquat is registered for crop-topping in WA lupin crops and can be applied at the 80 percent leaf drop point. Crop-topping at this time has been shown to minimise lupin yield losses in WA.⁵⁰

Short season varieties, such as PBA Gunyidi[®], Belara and Mandelup[®], typically reach 80 percent leaf drop stage seven to 10 days earlier than longer season varieties, such as Tanjil[®], and are well suited to crop-topping.

For annual ryegrass, crop-topping is most effective when the weed is at flowering to soft dough stage. If dough cannot be squeezed from the ryegrass seed, it will be viable even if crop-topping is used. In wet spring conditions, the duration of flowering and podding of the lupin crop can be extended due to the indeterminate growth habit of the crop. This prolongs the time until 80 percent leaf-drop and annual ryegrass can develop past the dough stage before the crop is ready. This highlights that crop-topping is a highly seasonally dependent tool that cannot be used each year unless lupin yield impact is accepted to ensure annual ryegrass is controlled.⁵¹

(For more information, see Chapter 10).

48 HerbiGuide, Wireweed, http://www.herbiguide.com.au/Descriptions/hg_Wireweed.htm

49 GRDC Fact Sheet (2015) Pre-harvest Herbicide Use, www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

50 GRDC Fact Sheet (2015) Pre-harvest Herbicide Use, www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

51 White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

i MORE INFORMATION

GRDC 'Know More' Video – Chaff carts for HWSC: <https://grdc.com.au/Video-KnowMore-West>

GRDC RCSN booklet 'The effectiveness of on-farm methods of weed seed collection at harvest time': www.grdc.com.au/CaseStudy-WeedSeedHarvest-Albany

WeedSmart 'HWSC guide and case studies': www.weedsmart.org.au/wp-content/uploads/2013/12/AHRI-Harvest-Weed-Seed-Control-Booklet_2013-version.pdf

WeedSmart webinar 'iHSD': at: <https://australianherbicide-resistance-initiative.leadpages.co/ws-webinar-recordings/>

5.9 Harvest weed seed control (HWSC) tactics



Figure 11: The new integrated Harrington Seed Destructor (iHSD) system is one HWSC method that destroys weed seeds by pulverising the chaff fraction as it leaves the harvester.

(SOURCE: McIntosh & Son)

A major biological weakness of most WA cropping weeds is their seed does not shatter before harvest, providing a good opportunity for removal at this time.

Capturing the weed seed and destroying it substantially reduces carry-over from the lupin crop into the next crop phase.

Common HWSC tactics used in WA include:

- » Collecting chaff in chaff carts
- » Burning or grazing chaff residue
- » Depositing chaff on narrow windrows for burning the next autumn
- » Using a seed destruction system to pulverise and destroy chaff and weed seed fraction as it leaves the harvester
- » Diverting weed seeds onto permanent tramlines
- » Towing a baler behind the header to remove all harvest residue.

These systems remove both resistant and susceptible weed seeds that have survived earlier herbicide applications. This reduces the risk of herbicide resistance evolution and the selection pressure on herbicides.

AHRI research at 25 sites across southern Australia during the 2010 and 2011 harvests found windrow burning, chaff cart and seed destruction systems were equally effective at removing annual ryegrass seed from cropping paddocks.

Each of these HWSC methods led to a 55 percent reduction in annual ryegrass germination the following year.

AHRI research has also shown that seed destruction at harvest consistently destroys 95 percent of annual ryegrass, wild radish, wild oats and brome grass seed present in the chaff fraction. Its trials in WA have also found chaff carts offer a reliable method of catching seed and are very effective at rapidly decreasing large banks of weed seed.⁵²

Typically, 45 to 75 percent of annual ryegrass seed and 70 to 80 percent of wild radish seed is collected in a chaff cart.

⁵² Walsh, M, Aves, C, Powles, S (2014) Evaluation of harvest weed seed control systems, AHRI, Nineteenth Australasian Weeds Conference paper, 4 GRDC Fact Sheet (2015) Pre-harvest Herbicide Use, <http://caws.org.au/awc/2014/awc201412881.pdf>

Baling behind the header can be a successful method to reduce weed seed banks. Trials have shown this can remove up to 98 percent of the weed seed that enters the header.

But increased mineral nutrient input is required to budget for exported nutrients in the straw and a powerful header is required to tow the baler.

To be viable, a market for the hay is needed – such as an export hay market or feed processing plant.

Burning entire paddocks on WA's sandplain soils needs to be carried out with extreme caution. This is generally undertaken very close to seeding, if at all, and is not recommended for lupin paddocks.

Burning lupin chaff that has been placed in a narrow windrow can be a more effective method than paddock burning to destroy annual ryegrass and radish seed.

The burn kills almost all the seed in the windrow. But seed that has dropped to the ground before going through the header is not controlled and it is best to harvest weedy paddocks first to minimise shedding of weed seed.⁵³

5.10 Weed detection technology



Figure 12: Yuna grower Craig Thompson bought a WEEDit precision sprayer seven years ago and says it has become a crucial tool for summer weeds control.

(SOURCE: GRDC)

Weed-detecting technology is being used in parts of WA, typically to target and spray individual weeds that survive a summer/autumn glyphosate application and an alternative knockdown herbicide.

This technology is well suited to detecting and killing patches of weeds across large-scale properties, using optical sensors to turn on spray nozzles only when green weeds are detected. This can reduce total herbicide use and cost per hectare (after accounting for the initial outlay cost for machinery).

This new technology also has potential to map troublesome weed patches so these areas can be targeted with a pre-emergent herbicide before sowing.

The two weed detecting systems available in Australia are WeedSeeker® and WEEDit®.

A minor use permit was issued for all Australian states for herbicide use with these systems and is valid until February 28, 2019 (to be reviewed annually).

The permit (PER11163) allows growers to use about 30 different selective grass herbicides from seven MOA groups and higher rates of paraquat and diquat.

⁵³ White, P, French, B, McLarty, A (2008) Producing Lupins, Department of Agriculture and Food WA, Bulletin 1-2008, <http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins>

MORE INFORMATION

RIM: www.ahri.uwa.edu.au/rim

RIM user guide: <http://ahri.uwa.edu.au/~ahriuwae/wp-content/uploads/2014/09/611-RIM-2013-User-guide.pdf>

DPIRD Weed Seed Wizard: <https://www.agric.wa.gov.au/weed-seed-wizard/weed-seed-wizard-download-and-help>

5.11 Decision support tools

Adoption of successful IWM involves complex interactions, multiple-year timeframes, many possible interventions, major environmental influences and high levels of uncertainty.

The use of computer-based models can be a valuable tool to aid decision making.

Developed by AHRI, with GRDC funding, the Ryegrass Integrated Management (RIM) model evaluates the long term profitability of annual ryegrass control methods and reducing the weed seedbank.

Weed Seed Wizard is a simulation tool, developed in a national collaboration, that uses paddock management information to predict weed emergence and crop losses now and in the future to help growers devise effective IWM plans.

5.11.1 Ryegrass Integrated Management (RIM)

RIM enables users to assess the effectiveness and budget implications of 10-year cropping and weed management scenarios using up-to-date economic parameters.

It has options for four crops, including lupin, three pastures and 43 practices that include herbicide use and rates, timing of application, soil preparation, crop type, grazing and HWSC options.

Graphs can be produced and exported to other software programs for analysing annual ryegrass survivors, gross margins across 10 years, yield loss from competition and ryegrass seedbank levels. See the link to this resource in the 'More information' box.

5.11.2 Weed Seed Wizard

This model can investigate the impact of a wide range of IWM strategies (such as HWSC, increased crop competition, rotation change and various seed set controls such as crop-topping and hay making) on weed and weed seed numbers.

It was developed by DPIRD in partnership with The University of Western Australia, University of Adelaide, the New South Wales Department of Primary Industries and the Department of Agriculture Fisheries and Forestry in Queensland, and supported by GRDC.

The user enters site-specific weather data and soil type, the weed species to be investigated and information about past and future weed management.

The model uses real weather data and gives an estimate of crop yield loss as a result of weed pressure from a range of species. See the link to this resource in the 'More information' box.

MORE INFORMATION

Integrated Pest Management Guidelines for Grains – Lupins: <http://ipmguidelinesforgrains.com.au/crops/winter-pulses/lupins/>

DPIRD 'Pulse crops – insect threshold levels': <https://www.agric.wa.gov.au/mycrop/pulse-crops-insect-threshold-levels>

DPIRD 'Managing insects, weeds and disease on albus lupin variety Andromeda': https://www.agric.wa.gov.au/search?search_api_views_fulltext=lupin%20insects

cesar 'PestFacts map': <http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/pestfacts-map/>

Control of pests and insects

6.1 Overview

Lupin crops tend to be more prone to insect and allied pest damage than cereal crops in Western Australia and need to be checked and monitored at critical stages of development.

Major insects and pests for narrow leafed and/or albus varieties in this State are:

Break of season to three-weeks after crop emergence

- Redlegged earth mite (RLEM, *Halotydeus destructor*)
- Cutworms (*Agrotis sp.*)
- Brown pasture looper (*Ciampa arietaria*)
- Lucerne flea (*Sminthurus viridis*)
- Bryobia mite (*Bryobia praetiosa*)
- Blue oat mite (*Penthaleus sp.*)
- Slugs
- Snails
- Balaustium mite (*Balaustium medicagoense*) – mainly in the southern region

Flowering

- Aphids (*Aphididae*)
- Thrips (*Thysanoptera*)

Pod fill

- Native budworms (*Helicoverpa punctigera*)
- Lucerne seed web moth (*Etiella behrii*) – rarely

Harvest and summer

- Snails as a grain contaminant.

Strategies to control these insects and pests will depend on presence and levels in the crop at that time.

An appropriate registered insecticide, often applied with a knockdown herbicide, can be effective for pre-seeding control if insects and pests are found on weeds before sowing.

If RLEM are not present on weeds before sowing, a bare-earth application just prior to crop emergence can be effective.

Monitoring for aphids should be carried out from crop budding through to early podding. A general rule-of-thumb is to apply an insecticide if more than 30 percent of crop plants have clusters of aphids visible and some leaves are beginning to curl from feeding damage.¹

¹ DPIRD-GRDC (2016) MyCrop Lupin diagnostic tool, Diagnosing aphids in narrow leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-aphids-narrow-leafed-lupins>

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Native budworm can be highly damaging to WA lupin crops during podding, especially for albus varieties, and a sweep net is particularly effective for monitoring numbers. The general rule-of-thumb is to use an insecticide if there is more than one budworm per 10 sweeps of a sweep net.² It is advised to sweep the crop in several locations across the paddock.

The timing of insecticide sprays in spring is critical for protecting lupin crop yields and, for native budworm, it is important not to wait for caterpillars to grow.

Snails and slugs can also be pests of lupin crops in WA, causing crop damage early in the season and grain contamination at harvest. Baits are available for control.

Guidelines for insecticide use thresholds on WA pulse crops (including lupin) are outlined in Table 1.

² DPIRD website (2016) Managing insects, weeds and disease in albus lupin variety Andromeda, <https://www.agric.wa.gov.au/lupins/managing-insects-weeds-and-disease-albus-lupin-variety-andromeda>

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Table 1: Insect threshold levels in pulse crops

Pest	Control thresholds	Sampling recommendation	Additional notes
Caterpillars			
Caterpillars: Brown pasture looper	10–12 loopers per m ²	Examine plants, old litter and soil surface in 0.5 m of row. Repeat at five to 10 sites	Larvae may migrate into crop edges from nearby capeweed.
Caterpillars: Cutworms	2–3 cutworm per m ²	Examine plants, old litter and soil surface in 0.5 m of row. Repeat at five to 10 sites	Apply as soon as pest is noticed at threshold levels.
Fleas			
Lucerne flea	Consider control measures if holes are increasingly being found on leaves	Inspect 0.5m of crop row. Look for characteristic holes in leaves. Repeat at five to 10 sites	Commonly found on soils with loam or clay texture.
Mites			
Balaustium mites	Look for silvering on extensive areas of cotyledons and leaves and stress caused to plants	Cotyledons and first true leaves appear silvered and 'leathery', sometimes may shrivel and seedling may die. Damage occurs post emergence.	Found on weeds, soil and seedlings.
Clover mite	Look for silvering on extensive areas of cotyledons and leaves and stress caused to plants	Same damage as Redlegged earth mite. White lines often seen on top of cotyledons. Seedling may shrivel and die.	Found on weeds, soil and seedlings.
Redlegged earth mite & Blue oat mite	Look for silvering on extensive areas of cotyledons and leaves and stress caused to plants	Cotyledons appear 'leathery', silver, twisted shrivelled and seedlings may die. Damage may occur before seedling emergence	Found on weeds, soil and seedlings.
Slugs:			
Black keeled slug			
Reticulated slug	10 or more slugs per m ²	They are found on plants at night or hidden under clods, trash or other objects during the day	Chewed leaves or whole plants. Sometimes feed on lupin seeds at seeding. Slime trails may sometime be seen.
Snails:			
White Italian snails Vineyard snail	Five or more snails per m ²	Found on leaves, stems or other nearby objects.	Look for chewed leaves, slime trails may sometimes be seen.
Small pointed snail	Three or more snails per m ²		

(SOURCE: <https://www.agric.wa.gov.au/mycrop/pulse-crops-insect-threshold-levels>)

i MORE INFORMATION

CropLife Australia 'Resistance Management': <http://www.croplife.org.au/industry-stewardship/resistance-management/>

GRDC Ground Cover Supplement 'Pest resistance drives need for IPM': <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-issue-94-SepOct-2011-Crop-Protection-Supplement/Pest-resistance-drives-need-for-IPM>

6.2 Integrated management

An Integrated Pest Management (IPM) plan is recommended for sustainable cropping systems in WA, taking into account:

- » Crop rotations – some rotations can support pest presence (long-term pasture paddocks are more susceptible to pests)
- » Soil preparation – summer and autumn cultivation or herbicide use can eliminate pest food sources
- » Sowing time – schedule planting windows when there is less likelihood of pest presence during critical crop development phases
- » Crop establishment – uniform crop establishment can help crops withstand pest attack, as can appropriately treated seeds
- » Crop choice and variety – varieties with inherited disease and pest resistance are preferable, particularly those with good seedling vigour and physiological features (such as hard seed coats) to deter pests
- » Weed management – insects use weeds as host plants and weed control should be considered for adjacent paddocks, fence lines and road sides (as well as in-crop control)
- » Disease management – insects can be disease transmitters and damage exposes crops to infestations. Diseased plants tend to be unable to compete with insect attack
- » Hygiene and sanitation – machinery, vehicles and people can carry insects and potential to move pests around should be minimised
- » Insecticide use – consider exposure of surrounding wildlife and insects
- » Environmental conditions – some weather, such as heavy rain, can affect the presence of insects on plants and may reduce the need for insecticide use.
- » Beneficial insect preservation – tolerate non-economic, early season damage and encourage beneficial insects into crops.

Incorporating cultural control measures with strategic insecticide use in the lupin phase of the crop rotation is important in reducing pest resistance risks as part of an IPM plan.

Research is finding an over-reliance on broad-spectrum insecticides and pesticides, such as synthetic pyrethroids (SPs), is resulting in development of resistance in pests such as Green peach aphid (*Myzus persicae*) and RLEM.

Researchers advise that more strategic pest management is required to control resistant populations and minimise the risks of resistance developing further.

Research is being carried out to map pesticide resistance in crop pest insects around Australia, along with further development and promotion of IPM practices.

The key IPM strategy for legumes, including lupin, is to avoid non-selective insecticides for as long as possible to foster a build-up of predators and parasites (with a national industry message to: 'go soft early').

This helps to keep early pests, such as aphids, in check, as predators can stop populations from building up.

However, intervention may be required during podding, especially against native budworm and aphid populations, which can peak during late pod fill.

 **MORE INFORMATION**

DPIRD 'MyEconomic Tool': <https://www.agric.wa.gov.au/wheat/myeconomic-tool>

GRDC 'The current and potential costs of invertebrate pests in grain crops': www.grdc.com.au/Resources/Bookshop/2013/02/The-current-and-potential-costs-of-invertebrate-pests-in-grain-crops

6.3 Economics of insect and pest control

Economic damage from insects and allied pests can occur in lupin during all crop growth stages.

The lupin plant can compensate for moderate damage that occurs early in development by setting new buds and pods to replace those lost.

But excessive early damage can reduce yield and potentially delay harvest.

A useful decision support calculator called MyEconomic Tool has been developed that can help assess the risks and costs of a range of insect treatment options for use in lupin (and other broadacre crops).

It takes into account expected treatment costs, potential crop yield, commodity prices and input costs to analyse a range of scenarios.

A 2013 GRDC-funded report, 'The current and potential costs of invertebrate pests in grain crops', studied the costs of control measures for major insect pests across Australia.

In the western region, potential economic loss to the State's grain growers from major insect and allied pests (when cultural and chemical practices are not used) was estimated at:

- » RLEM – \$21.62 per hectare, or \$11.6 million
- » Cutworm – \$1.08/ha or \$0.6m
- » Lucerne flea – \$3.24/ha or \$1.7m
- » Bryobia/balaustium mite – \$1.62/ha or \$0.9m
- » Aphids – \$9.73/ha or \$5.2m
- » Budworms – \$14.59/ha or \$7.9m
- » Snails – \$0.95/hectare or \$0.5 million
- » Total costs from invertebrate pests: \$58.51/ha or \$31.5 million.

(SOURCE: GRDC report 'The current and potential costs of invertebrate pests in grain crops', 2013)³

The 2013 GRDC report found the average cost of treating all insects and pests in WA lupin crops was \$15.20/ha, or \$8.2m annually.⁴

It outlined that action thresholds drive treatment for most pests, but very few of these have been derived from empirical (observation and experience) analysis.

The report recommended the economic benefits of controlling pests should be weighed-up carefully by growers and advisers as part of an IPM plan, as chemical costs per pest can be high. This is illustrated in Table 2.

³ Murray, Dave, Clarke, Michael, Ronning, David (2013) The current and potential costs of invertebrate pests in grain crops', <https://grdc.com.au/Resources/Bookshop/2013/02/The-current-and-potential-costs-of-invertebrate-pests-in-grain-crops>

⁴ Murray, Dave, Clarke, Michael, Ronning, David (2013) The current and potential costs of invertebrate pests in grain crops', <https://grdc.com.au/Resources/Bookshop/2013/02/The-current-and-potential-costs-of-invertebrate-pests-in-grain-crops>

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Table 2: Representative pesticide treatment used and cost – lupin

Invertebrate pest	Representative pesticide control	Active ingredient	Chemical cost per ha
Snails			
Snails (various)	baits	metaldehyde	\$12.00
Mites			
Redlegged earth mite	PSPE	bifenthrin	\$1.60
Blue oat mite	PSPE	bifenthrin	\$1.60
Bryobia (various) / Balaustium mite	presowing and knockdown	omethoate	\$1.90
Springtails			
Lucerne flea	PSPE	omethoate	\$1.90
Aphids			
Aphids (various)	dimethoate	dimethoate	\$6.25
Caterpillars			
Etiella moth	SP	alpha-cypermethrin	\$2.55
Budworms	SP	alpha-cypermethrin	\$2.55
Cutworms (various)	SP	alpha-cypermethrin	\$0.64
Weed web moth	SP	alpha-cypermethrin	\$2.55
Beetles			
Weevils (various)	SP	alpha-cypermethrin	\$0.85
Earwigs			
European earwigs	no treatment*		
Additional Pests (N/A)			

PSPE: post sowing pre-emergent, SP: Synthetic pyrethroid * Controls may be permitted under relevant State Pesticide Regulations

Source: © State of Queensland, 2016. The information contained herein is subject to change without notice. The Queensland Government shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from using this information.

i MORE INFORMATION

CSIRO 'Insect identification resources online': <http://www.csiro.au/en/Research/Collections/ANIC/ID-Resources>

GRDC 'Ute Guide – Insects': <https://grdc.com.au/Resources/Ute-Guides/Insects>

DPIRD-GRDC MyCrop: <https://www.agric.wa.gov.au/mycrop>

TimeRite®: www.timerite.com.au

GRDC 'Back Pocket Guide – Crop Mites': www.grdc.com.au/BPG-CropMites

cesar 'Redlegged earth mite': <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite>

DPIRD 'Diagnosing Redlegged earth mite': <https://www.agric.wa.gov.au/mycrop/diagnosing-redlegged-earth-mite>

GRDC Fact Sheet 'RLEM Resistance Management Strategy – Western': <https://grdc.com.au/FS-RLEM-Resistance-strategy-West>

6.4 Pest identification and management – seedling stage

6.4.1 Redlegged earth mites, RLEM (*Halotydeus destructor*)



Figure 1: Redlegged earth mites are a serious pest of lupin crops.

(SOURCE: © Western Australian Agriculture Authority (Department of Agriculture and Food, WA))

Redlegged earth mites (RLEM) are about the size of a pin head (up to 1 mm), with a velvety black body and eight red-orange legs.

These mites spend about 90 percent of their time on the soil surface, rather than on plant foliage, but will feed on crop foliage for short periods before moving around to settle at the next feeding site.

In WA, RLEM are most active between April and November and can have up to three generations in a year.

At the end of spring, the mites lay thick-walled, over-summering eggs that can resist dry summer conditions and carry the mite population into the next season.

Mites hatch from the over-summering eggs after adequate exposure to moisture and low temperatures.

Lupin crops are most susceptible to RLEM damage as young seedlings and when there are high numbers of mites. The mites cluster, rupture cells and suck the juices out of the leaves, giving them a leathery and silvery appearance.

But lupin has large, robust cotyledons and can be relatively tolerant of RLEM, often growing away from any damage caused.

Severe symptoms of RLEM damage in lupin crops include white bleached leaves and slow growth. A heavy infestation of RLEM may reduce plant density, retard the development of the crop or even kill seedlings.

Monitoring

Recommendations for monitoring RLEM in lupin crops include:

- » Inspect crops in the first three to five weeks after sowing
- » Inspect crops from autumn to spring for mite presence and damage
- » Look for mites early in the morning or on overcast days
- » Consider control if plants are not outgrowing damage.

Control

It is advised that RLEM control in WA lupin crops is best started in the spring of the year prior to sowing.

The aim is to reduce mite numbers and the number of over-summering eggs produced to depress populations hatching the following autumn.

Strategies to achieve this include:

- » In-crop weed control to reduce mite food sources
- » Grazing pastures in spring to less than 2 tonnes per hectare of feed on offer (dry weight)
- » Spray insecticide before summer eggs are laid using the TimeRite® package (if in a pasture phase).

Early sown lupin crops have the best chance of establishing before populations of RLEM increase to damaging levels.

Lupin seed can be treated with systemic insecticides to protect seedlings, especially when there are low-moderate mite numbers.

Compatible insecticides can be applied with a knockdown herbicide or as a bare earth spray prior to crop emergence.

Typically in WA, it is only necessary to use a foliar insecticide for RLEM if lupin crops are not growing away from damage.

Researchers have detected RLEM with resistance to SPs in WA and tolerance to the organophosphates (OPs) chlorpyrifos and omethoate (the only state in Australia with this problem to date) and this is a risk growers need to manage.⁵

GRDC released a new Fact Sheet in mid-2016 that contains an overview of the latest advice about IPM tactics to deal with RLEM resistance issues. It can be found at this link <https://grdc.com.au/FS-RLEM-Resistance-strategy-West>

It is advised to rotate chemical groups in and between seasons, avoid prophylactic sprays and apply insecticides only if control is warranted.

Insecticides used at, or after, sowing should be applied within three weeks of the first appearance of mites, before adults start laying eggs. Insecticides do not kill mite eggs. Treating paddock fence lines and borders can be an effective way to control mites and pre and post-sowing weed management, particularly of broadleaf weeds, is vital when growing lupin. Non-chemical control options for RLEM include grazing during summer with livestock or sowing non-susceptible crops, such as barley, in the rotation.⁶

Approved insecticide actives for the control of RLEM in lupin crops in the western region include:

- Lambda-cyhalothrin
- Gamma-cyhalothrin
- Alpha-cypermethrin
- Chlorpyrifos
- Methidathion
- Bifenthrin.

5 DPIRD website (2016) Prevent redlegged earth mite resistance, <https://www.agric.wa.gov.au/mites-spiders/prevent-redlegged-earth-mite-resistance>

6 DPIRD website (2016) Diagnosing redlegged earth mite, <https://www.agric.wa.gov.au/mycrop/diagnosing-redlegged-earth-mite>

i MORE INFORMATION

DPIRD ‘Cutworm: pests of crops and pastures’: <https://www.agric.wa.gov.au/pest-insects/cutworm-pests-crops-and-pastures>

DPIRD ‘Diagnosing cutworm in canola and pulses’: <https://www.agric.wa.gov.au/mycrop/diagnosing-cutworm-canola-and-pulses>

IPM Guidelines ‘Cutworms’: <http://ipmguidelinesforgains.com.au/pests/soil-insects/cutworms/>

cesar Australia ‘Cutworms’: <http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern-past-issues/2014/pestfacts-issue-no-4-5th-june-2014/cutworms/>

PIRSA ‘Cutworm alert’: http://www.pir.sa.gov.au/research/services/reports_and_newsletters/pestfacts_newsletter/pestfacts_issue_3_2016/cutworm_alert_for_the_sa_mallee

6.4.2 Cutworms (*Agrotis* spp.)



Figure 2: Larvae of cutworms can feed on young plants and stems at or below the soil surface and often cut off entire plants.

(SOURCE: SARDI)

Cutworms are plump, smooth-bodied caterpillars of several moth species that grow to about 50 mm in length and are pinkish-brown to black in colour.

Heads are slightly darker and these pests have dark lines or spots along their body and curl up and remain still if disturbed.

Cutworms hide under the soil or litter in the day and feed at night, causing damage to emerging and seedling lupin at or below the soil surface.

When young, cutworms feed on the surface tissue of foliage and, when older, earn their name by eating plants off at the stem.

These pests are most damaging in autumn, when large caterpillars (more than 20 mm in length) transfer from summer and autumn weeds to newly emerged crop seedlings.

Control

Control measures for cutworms in WA lupin crops include:

- » Remove any green bridge of weeds or crop volunteers two weeks before planting lupin
- » Monitor closely early in the season, as these pests can be hard to find and numbers easily under-estimated
- » If necessary, apply registered insecticides
- » Label rates of SPs are effective
- » Spot-spraying affected areas often provides adequate control.

Approved insecticide actives for use on cutworm in lupin crops in the western region include:

- Zeta-cypermethrin
- Esfenvalerate
- Deltamethrin
- Cypermethrin
- Beta-cypermethrin
- Alpha-cypermethrin.

DPIRD’s MyEconomic Tool can help calculate the economic risks and financial costs of various treatments for cutworm. See: <https://www.agric.wa.gov.au/wheat/myeconomic-tool?type=Cutworm>

It advises any management plan for this pest should take into account:

- » Potential yield losses associated with cutworm feeding damage
- » Costs and benefits of taking preventative action
- » Costs and benefits of controlling summer weeds (green bridge)
- » Costs, benefits and risks of in-crop management, versus doing nothing or delaying treatment
- » Assessing the impact of a range of grain price and seasonal conditions on net income
- » Costs and benefits of an IPM system, including resistance management.

(SOURCE: DAFWA)

MORE INFORMATION

DPIRD-GRDC MyCrop 'Brown pasture looper': <https://www.agric.wa.gov.au/mycrop/diagnosing-brown-pasture-looper>

6.4.3 Brown pasture looper (*Ciampa arietaria*)

The brown pasture looper is a grey or dark-brown caterpillar, with yellow lines along its back on either side of a dark band, and chews seedling lupin crops.

Young caterpillars move with a characteristic looping motion, which stops when at full size (about 35 mm in length).

Eggs are laid in early to mid-autumn and hatched caterpillars grow to full size in about two months, after which they pupate and remain in the pupal stage during spring and summer to later emerge as moths in the following season. Brown pasture loopers are most damaging as large (more than 20 mm in length) caterpillars in autumn.

Often this pest is found around crop edges, having moved in from adjacent pasture or rock heaps.

Affected lupin crops will have leaves chewed from the edges.

Control

Control measures for brown pasture loopers in WA lupin crops include close paddock inspection, especially in weedy areas, and – if necessary – use of insecticides.

Registered products for control in WA lupin crops include:

- Bifenthrin
- Esfenvalerate
- Gamma-cyhalothrin
- Lambda-cyhalothrin.

i MORE INFORMATION

DPIRD 'Diagnosing Lucerne flea': <https://www.agric.wa.gov.au/mycrop/diagnosing-lucerne-flea>

IPM Guidelines 'Lucerne flea': <http://ipmguidelinesforgrains.com.au/pests/lucerne-flea-in-winter-seedling-crops/>

GRDC Hot Topic 'Beating the Lucerne flea': <https://grdc.com.au/Media-Centre/Hot-Topics/Beating-the-lucerne-flea>

cesar Australia 'Lucerne flea': <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea>

6.4.4 Lucerne flea (*Sminthurus viridis*)



Figure 3: Lucerne flea typically moves up the lupin plant from ground level, eating tissue from the underside of foliage.

(SOURCE: Andrew Weeks, cesar)

Lucerne fleas are small jumping insects that appear early in the season, commonly on WA's loam-clay soils, and chew on young leaves of lupin crops, other broadleaf crops and legume pastures.

Adults grow to about 3 mm and are yellow-green in colour, wingless and have a furcula underneath the abdomen – allowing them to spring off vegetation when disturbed. This trait gives the insect its common name of 'spring tails'.

In WA, lucerne fleas are often distributed in patches in paddocks and across a region, but favour heavy soil types and are rare on sandy soils with low clay contents. In cool moist conditions, this pest can produce up to five generations each year.

Lucerne fleas hatch from over-summering eggs after the first soaking rains in autumn.

They move up plants from ground level, eating tissue from the underside of foliage and leaving behind a thin clear layer of membrane that appears as transparent windows through the leaf.

In severe infestations, this damage can skeletonise the leaf and stunt or kill plant seedlings.

Lupin crops are most susceptible at the time of emergence and early signs of damage include chewed leaflet spots and edges.

Control

Management options for lucerne flea in WA lupin crops include:

- » Effective weed control in spring to reduce the green bridge
- » Grazing management of pastures in spring to suppress populations
- » Border sprays or spot-spraying if required
- » If required, use of the approved insecticide methidathion.

It is advised to calculate the economic value of controlling lucerne flea in lupin crops, taking into account potential yield losses from feeding damage, costs of preventative action, risks of doing nothing and costs of summer weed control.

The MyEconomic Tool decision-support calculator on the DPIRD website can help with this process.

i MORE INFORMATION

DPIRD-GRDC MyCrop 'Bryobia mite':
<https://www.agric.wa.gov.au/mycrop/diagnosing-bryobia-mite>

i MORE INFORMATION

DPIRD-GRDC MyCrop 'Balaustium mite': <https://www.agric.wa.gov.au/mycrop/diagnosing-balaustium-mite>

HerbiGuide 'Balaustium mite':
http://www.herbiguide.com.au/Descriptions/hg_Balaustium_Mite.htm

6.4.5 Bryobia mite or clover mite (*Bryobia praetiosa*)

Bryobia mite, also known as clover mite, is reddish-grey and grows to 1 mm in size, with red legs and two long forelegs. These pests can be confused with RLEM.

Over-wintering eggs of bryobia mite are typically laid in early to mid-winter and hatch as conditions warm up in spring.

As pastures deteriorate in late spring or summer, over-summering eggs are produced and these hatch as soon as there is sufficient moisture for plants to germinate at the break of the next season.

Adult bryobia mites are most active in warm conditions, especially in autumn, late spring and summer, and tend not to survive cold winters or very dry summers.

In areas protected from these extremes, all life stages of the mites may be present in the lupin crop if there is sufficient green plant material available.

Bryobia mites create long trails of whitish grey spots on the top of cotyledons and the leaf surface. This differs from RLEM, which cause silvering on leaves.

Damage is more severe when seedlings are stressed, such as an autumn or winter drought.

The mites can become a serious pest of lupin crops in years when there are early autumn rains that facilitate weed growth and early establishment of mite populations.

Bryobia mite is difficult to control, especially if insecticides are targeted to stop damage to crops at emergence.

A more effective option is killing all weeds well before seeding and/or applying a miticide to weeds with knockdown herbicides if the crop is not out-growing pest damage.

The registered active for control in WA lupin crops is bifenthrin.

6.4.6 Balaustium mites (*Balaustium medicagoense*)



Figure 4: The balaustium mite adult reaches about 2 mm in length, with a rounded dark red-brown body and red legs with distinct short hairs on the body.

(SOURCE: SARDI)

This mite grows to about 2 mm in length as an adult, about twice the size of RLEM and bryobia mite.

It has a rounded dark red-brown body with distinct short hairs and red legs and is more common in southern agricultural regions.

Balaustium mites survive throughout the year if there is green plant material and typically produce two generations.

Over-summering eggs are laid in late spring or summer, as pastures deteriorate, and hatch the next year when there is sufficient moisture for plants to germinate.

Unlike the eggs of RLEM, the eggs of balaustium mites do not require cold temperatures to stimulate hatching.

Balaustium mites typically attack leaf edges and leaf tips of plants and, in lupin crops, damage is seen as irregular white spotting on cotyledons and leaves – giving a ‘leathery’ and silver appearance.

If mites are present in high numbers, leaves and cotyledons may be bleached. Lupin crops are usually able to grow away from balaustium mite damage.

Early control of summer and autumn weeds, especially capeweed (*Arctotheca calendula*) and grasses, can suppress mite populations.

There are no registered pesticide actives to control balaustium mites in WA lupin crops.

MORE INFORMATION

DPIRD-GRDC MyCrop ‘Diagnosing blue oat mite’: <https://www.agric.wa.gov.au/mycrop/diagnosing-blue-oat-mite>

http://www.pir.sa.gov.au/_data/assets/pdf_file/0004/274090/Blue_oat_mite.pdf

6.4.7 Blue oat mite (*Penthaleus major*)



Figure 5: Blue oat mite are dark purple or blue with a red spot and can cause discoloration of crop leaves.

(SOURCE: Andrew Weeks, cesar)

WA lupin crops are vulnerable to blue oat mites, particularly at the seedling stage. But crops can typically grow away from any damage caused by the mite when seasonal conditions are good.

Blue oat mites often co-exist with RLEM and can be confused with this pest, as they are a similar size of about 1 mm in length and have eight orange legs. But the blue oat mite is a dark purple/blue colour with a distinctive red spot on the back.

This mite is active in autumn, winter and spring and has a similar life cycle to RLEM, but can produce up to four generations each year that last for eight to 10 weeks.

Over-summering eggs hatch in autumn, stimulated by cold temperatures and adequate moisture.

Mite damage is common in early sown crops in years with summer rain and a green bridge.

Signs of damage in lupin crops includes cotyledons with a leathery and silvery appearance, bleached leaves and sometimes death of seedlings when numbers are high.

Insecticide and cultural controls are available for blue oat mite, but this mite has a higher natural tolerance to some actives.

To prevent population build up, insecticides are best applied at full registered rates within three weeks of the first appearance of mites before adults start laying eggs.

The currently registered insecticide for blue oat mite – chlorpyrifos – is only effective on active stages of mites.

For low-moderate mite populations, insecticide seed dressings can be an effective method of control.

It is recommended to avoid prophylactic sprays; apply insecticide only if control is warranted and mite identity is positive.

When monitoring for blue oat mites, consider these insects are active in winter and spring, hatching in autumn from summer-laid eggs.

Mites are most easily seen in the late afternoon when they begin feeding on leaves. Check from planting to early vegetative stage, particularly in dry seasons.

6.5 Pest identification and management – flowering stage

6.5.1 Aphids (*Aphididae*)



Figure 6: Aphids are a pest of lupin crops at the flowering stage.

(SOURCE: © Western Australian Agriculture Authority (Department of Agriculture and Food, WA))

The three types of aphids responsible for the bulk of infestations in WA lupin crops are Cowpea aphids (*Aphis craccivora*), Blue green aphids (*Acyrtosiphon kondoi*) and Green peach aphids (*Myzus persicae*).

Less common are Leafcurl plum aphid (*Brachycaudus helychrisi*) and Potato aphid (*Macrosiphum euphorbiae*).

Cowpea aphids are charcoal grey to shiny black and tend to colonise single plants or groups in 'hot spots'.

Blue green aphids are about the same colour as lupin leaves and typically distribute more evenly through the crop, but can congregate on some plants in larger population sizes.

Green peach aphids are pale green, similar to the colour of the lupin stem, and are usually found on the underside of older lupin plant leaves. These usually cause less feeding damage to lupin than other aphid species.

Lupin crops are rarely attacked by other species of aphids, but the WA grains industry is closely monitoring the incidence of Russian wheat aphid (RWA, *Diuraphis noxia*) in other states. This pest is potentially a severe crop threat – especially for susceptible cereal crops.

MORE INFORMATION

GRDC 'Ute Guide – Crop insects': <https://grdc.com.au/Resources/Ute-Guides/Insects>

GRDC 'Tips and Tactics – Reducing aphid and virus risk': <https://grdc.com.au/Resources/Factsheets/2015/02/Reducing-aphid-and-virus-risk>

GRDC 'Back Pocket Guide – Crop Aphids': <https://grdc.com.au/Resources/Bookshop/2015/02/Crop-Aphids-Back-Pocket-Guide>

DPIRD 'Management of aphids in Western Australian lupin crops': <https://www.agric.wa.gov.au/grains-research-development/management-aphids-western-australian-lupin-crops>

DPIRD 'Russian wheat aphid': agric.wa.gov.au/rwa2016

IPM Guidelines 'Aphids in pulses': <http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-pulses/>

Monitoring

Aphids grow to about 3 mm in length, can be winged or wingless and are most likely to colonise the edges of crops first.

For this reason, it is recommended growers monitor a 20-metre border of paddocks for the first signs of aphids or crop damage from this insect.

When checking crops, it is best to get a close look by getting on hands and knees and inspecting the leaves down to the crown of the plant, where aphids may be hiding.

WA growers can use the GRDC-DPIRD MyPestGuide Crops application (smart technology app) to identify aphid species, size and crop damage symptoms.⁷

Control

It is advisable to treat crops according to aphid thresholds to avoid unnecessary or prophylactic sprays.

The threshold for aphid control with insecticide to produce a yield response in WA lupin crops is when 30 percent of flowering buds have more than 30 aphids.⁸

These estimates are based on assessing plants in numerous parts of the lupin crop paddock and inspecting flowering heads at random, looking for insect clusters and symptoms of leaf curling.

It is advisable when deciding to treat crops to consider other beneficial insects, such as hover flies (*Syrphidae*), ladybirds (*Coccinellidae*), lacewings (*Chrysopidae*) and parasitic wasps (*Braconidae*) that attack aphids and keep populations low. Using sprays that target aphids only can leave beneficial insects unharmed.

Aphids cause the bulk of damage to lupin crops before plant symptoms are obvious. By the time symptoms are visible, yield loss that cannot be recovered by insecticide control may have occurred.

Crop yields are affected by direct aphid feeding damage causing flower and pod abortion during budding and flowering.

Aphids are also vectors of the damaging Cucumber mosaic virus (CMV) and Bean yellow mosaic virus (BYMV) in WA lupin crops.

Winged aphids fly into lupin crops from surrounding vegetation and pastures.

Spring population sizes will depend on autumn and winter conditions.

Long autumn growing periods allow early build-up and spread of aphids.

Mild (not cold) winters allow further development and spread of winged aphids, which can establish many small colonies of wingless aphids in a crop.

Some lupin varieties are more susceptible to aphid feeding damage than others, as shown in Table 3.

Without control, research indicates aphid damage in susceptible varieties can be as high as 90 percent and damage to varieties with intermediate resistance can be up to 30 percent.⁹

7 DPIRD website (2016) The MyPestGuide Suite, <https://www.agric.wa.gov.au/biosecurity/mypestguide-suite>

8 DPIRD-GRDC (2016) MyCrop Lupin diagnostic tool, Diagnosing aphids in narrow leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-aphids-narrow-leafed-lupins>

9 DPIRD-GRDC (2016) MyCrop Lupin diagnostic tool, Diagnosing aphids in narrow leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-aphids-narrow-leafed-lupins>

Table 3: Susceptibility of narrow leaved lupin varieties grown in Western Australia 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
Belara	S	MS	S
Coromup [Ⓛ]	R	MR	MS
Jenabillup [Ⓛ]	R	MRMS	MR
Mandelup [Ⓛ]	R	MRMS	S
PBA Barlock [Ⓛ]	R	MR	MS
PBA Gunyidi [Ⓛ]	R	MRMS	MS
PBA Jurien [Ⓛ]	R	MRMS	MR
Quilinock [Ⓛ]	MS	MR	MR

Key: VS=very susceptible, S=susceptible, MS= moderately susceptible, MR=moderately resistant, R=resistant, VR=very resistant. (SOURCE: Pulse Breeding Australia.)

Management strategies for controlling aphids in WA lupin crops include:

- » Sowing healthy seed
- » Using high seeding rates to generate dense stands
- » Putting cereal barriers around the crop
- » Heavy grazing of adjoining pasture paddocks to reduce aphid numbers
- » Strategic aphicide sprays
- » Delaying spraying if a cold front is expected
- » Using 'soft' products, such as pirimicarb, that are aphid-specific
- » Considering short-term residual sprays
- » Considering a barrier spray only (crop edges)
- » Considering stubble retention (repels aphids from landing)
- » Ensuring good weed control to avoid a green bridge between seasons
- » Encouraging aphid predators and parasites.

Some WA Green peach aphid (GPA) populations are resistant to pyrethroids (Group 3A), OPs (Group 1B) and carbamates (Group 1A). But the level of resistance to OPs appears to have plateaued in WA, according to researchers.¹⁰

Testing of populations of GPA across southern Australia in 2016 found resistance to neonicotinoid insecticides (commonly used in seed treatments) for the first time.

To assist growers with GPA management strategies, the GRDC has collaborated with **cesar**, the South Australian Research and Development Institute (SARDI – a division of Primary Industries and Regions South Australia, or PIRSA), the New South Wales Department of Primary Industries (NSW DPI) and the Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR) to produce a 'Tips and Tactics' publication focused on 'Reducing aphid and virus risk'. It can be found at: <https://grdc.com.au/Resources/Factsheets/2015/02/Reducing-aphid-and-virus-risk>

The industry 'Resistance management strategy for GPA in Australian grains' can be viewed at: <http://ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies/>

¹⁰ GRDC (2015) Tips and Tactics 'Reducing aphid and virus risk', <https://grdc.com.au/Resources/Factsheets/2015/02/Reducing-aphid-and-virus-risk>

i MORE INFORMATION

GRDC 'Ute Guide – Insects': <https://grdc.com.au/Resources/Ute-Guides/Insects/Thrips/South/Onion-Thrips-Plague-Thrips-and-Western-Flower-Thrips>

DPIRD-GRDC MyCrop 'Thrips': <https://www.agric.wa.gov.au/mycrop/diagnosing-thrips-lupins>

i MORE INFORMATION

DPIRD 'Diagnosing native budworm in narrow-leafed lupins': <https://www.agric.wa.gov.au/mycrop/diagnosing-native-budworm-narrow-leafed-lupins>

DPIRD 'Management and economic thresholds for native budworm': https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm?page=0%2C4#smartpaging_toc_p4_s1_h3

DPIRD 'Albus lupins': <https://www.agric.wa.gov.au/lupins/amira-anthraco-resistant-albus-lupin-western-australia?page=0%2C2>

IPM Guidelines 'Native budworm in winter pulses': <http://ipmguidelinesforgrains.com.au/pests/helicoverpa/native-budworm-in-winter-pulses/>

Approved insecticides for control of aphids in WA lupin crops include:

Cowpea aphid

- Methidathion
- Dimethoate.

Blue green aphid

- Dimethoate.

Green peach aphid

- Pirimicarb
- Petroleum oil
- Paraffinic oil (suppression only)
- Omethoate (suppression only)
- Dimethoate.

6.5.2 Thrips

Adult onion thrips (*Thrips tabaci*) and plague thrips (*Thrips imagines*) are 2 mm long, cigar-shaped insects that affect WA lupin crops.

These pests range in colour from yellowish-orange to dark grey and it is difficult to differentiate between the two species in the field.

Thrips breed all year round on green plant material, especially flowering plants, piercing plant tissue and sucking sap.

This leads to distorted leaves and, in extreme cases, high numbers at the flowering stage of the lupin crop may cause flower abortion.

But, in WA, this pest rarely causes damage that is sufficient to warrant control measures.

6.6 Pest identification and management – pod fill stage

6.6.1 Native budworm (*Helicoverpa punctigera*)



Figure 7: The larvae of native budworm are shades of orange, brown and green with dark stripes on the body.

(SOURCE: SARDI)

Native budworm (*H. punctigera*) is a major insect pest in WA lupin crops, especially in the South West region. The caterpillar can cause serious yield loss as pods mature in late winter and spring.

These caterpillars grow to about 40 mm in length in seven weeks from egg hatching and are shades of orange, brown and green – typically with dark stripes on the body.

SECTION 6 LUPIN

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FEEDBACK

Adult moths are about 15-18 mm in length and a buff, light brown to red-brown colour, with numerous dark spots and blotches.

The hind wings of the adult moth are pale with a dark band along the lower edge and span 30-35 mm. Migratory flights of these moths are unpredictable and they can be carried by air currents for hundreds of kilometres.

Native budworm caterpillars feed on lupin plant leaves and stems until the crop nears maturity, at which time they are attracted to the pods.

When about 15 mm in length, the caterpillars can drill through the pod wall and eat the seeds.

At the final two growth stages (fifth and sixth instar), the caterpillars tend to eat more than 90 percent of their total grain consumption.

New moth flights and egg laying will result in caterpillars of varying sizes in a crop at any one time.

Crop losses occur from direct seed weight loss (through being partly or wholly eaten after sowing) and/or downgraded grain quality from unacceptable levels of chewed grain or fungal infections from caterpillar entry to the pod.

Damage to narrow leafed lupin typically occurs when plants are close to maturity and the pods are losing their green colour. Signs of infestation include chewed leaves, flowers and pods.

Native budworm is potentially the most serious seed insect pest of Amira[®] and Andromeda[®] albus lupin, affecting the podding of these varieties.

DPIRD monitors the numbers of native budworm moths through pheromone (female sex scent) traps spread across the WA grainbelt and results are published regularly through its PestFax service.

It advises that on-farm monitoring for native budworm numbers is best carried out by sweeping with an insect net.

Recommendations for effective sweeping include:

- » Use a standard insect net that is 380 mm in diameter
- » Taking 2-m wide, long sweeping arc sweeps
- » Taking multiples of 10 sweeps in several parts of the lupin crop
- » Checking short and thin areas for highest efficiency of sweeping
- » Keeping the lower leading edge of the sweep net slightly forward of the opening.

Monitor

Monitoring to gauge the size and age of caterpillars should start well before damage to pods is expected.

Large caterpillars will damage the lupin as it drops its leaves and caterpillars begin to feed on the pods.

If the population is made up of large, ageing caterpillars when the lupin plant still has leaves, treating with insecticide may not be necessary – as the caterpillars may pupate before pod damage occurs.

But if large numbers of small caterpillars are present before leaf drop, spraying may be required – as these caterpillars will mature just as the lupin plant drops its leaves and pod damage may occur.

An alternative to sweeping for crop monitoring, especially in dense crops or where plants are too stiff and pods too spikey, is to cut plants from the base in several parts of the crop paddock and, at each sample point, shake these into a bin to count caterpillar numbers. About 40 plants is equivalent to one square metre of crop.

This is considered the easiest method for assessing damage levels for the entire crop.

Control

Threshold levels for economic control of native budworm in narrow leafed lupin varieties at prices of about \$300 per tonne and insecticide costs of about \$8 per hectare (for product and application) are about six grubs of 15 mm or longer per 10 sweeps.¹¹

If the price of grain increases, or the cost of application decreases, the economic threshold levels decrease.

At times, losses from native budworm can be less than predicted, if, for example, the season is shortened by a lack of moisture.

Spray thresholds have not yet been developed for Amira[®] or Andromeda[®] albus varieties in WA, but the rule-of-thumb is to spray insecticide if there is more than 1 budworm per 10 sweeps.¹²

The timing of insecticide sprays is critical for protecting albus lupin yields and it is recommended not to wait for caterpillars to grow.

For both narrow leafed and albus lupin, a decision to spray an insecticide on a lupin crop for native budworm control should not be made until damage is about to occur and pods are beginning to mature.

Effective control requires understanding when the crop is at risk and the economic threshold for when to spray.

Natural mortality of budworm populations is sometimes sufficient to prevent economic damage and monitoring should continue around crop maturity and podding.

Registered insecticides for controlling native budworm in WA lupin crops include:

- Zeta-cypermethrin
- Spinetoram
- Nuclear polyhedrosis virus of *helicoverpa armigera*
- Methomyl
- Lambda-cyhalothrin
- Esfenvalerate
- Deltamethrin
- Cypermethrin
- Beta-cypermethrin
- *Bacillus thuringiensis* subsp *kurstaki* strain HD-1
- Alpha-cypermethrin.

¹¹ DPIRD website (2016) MyCrop diagnosing native budworm, <https://www.agric.wa.gov.au/mycrop/diagnosing-native-budworm-narrow-leafed-lupins>

¹² DPIRD website (2016) Managing insects, weeds and disease in albus lupin variety Andromeda, <https://www.agric.wa.gov.au/lupins/managing-insects-weeds-and-disease-albus-lupin-variety-andromeda>

i MORE INFORMATION

IPM guidelines 'Etiella':
<http://ipmguidelinesforgrains.com.au/pests/etiella/>

cesar Australia 'Lucerne seed web moth or Etiella': <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-seed-web-moth-or-Etiella>

Pest Web 'Etiella moth': http://agpsrv34.agric.wa.gov.au/ento/pestweb/Query1_1.idc?ID=1701059111

6.6.2 Lucerne seed web moth (*Etiella behrii*)



Figure 8: The lucerne seed web moth is grey-brown, up to 12 mm long with a protruding 'beak' and is a sporadic pest of lupin crops. Pictured is its larvae.

(SOURCE: SARDI)

Lucerne seed web moths grow to about 20 mm, are grey-brown with a stripe on each forewing and have an orange band across the wing base.

In WA, this pest is rare and sporadic and removing early season volunteer legume plants near lupin crops may provide sufficient control.

Lucerne seed web moths produce three to four generations each year in spring, summer and autumn and newly hatched larvae feed on the seed in lupin crop pods.

Damaged seeds have jagged edges, similar to native budworm damage, but are distinguished by the presence of webbing in the pod.

In most seasons, this pest causes only minor damage to seed. It is only in years when numbers are high that significant yield losses have been reported.

Monitoring for lucerne seed web moth in lupin crops should focus on detecting the presence of webbing in flowers and in the growing points of the plant.

Early detection is important, but lucerne seed web moths do not usually cause economic damage in WA lupin crops – unless there are crops growing over summer (for example, lucerne) that host the pest and allow numbers to build-up.

i MORE INFORMATION

GRDC 'Fact Sheet – Snail management': <https://grdc.com.au/Resources/Factsheets/2012/09/Snail-Management>

GRDC 'Hot Topic – New insights to give snails and slugs the slip': <https://grdc.com.au/Media-Centre/Hot-Topics/New-insights-to-give-snails-and-slugs-the-slip>

GRDC 'Ute Guide – Insects: slugs and snails': <https://grdc.com.au/Resources/Ute-Guides/Insects/Slugs-snails>

GRDC 'Ground Cover TV snail and slug playlists': <http://www.grdc.com.au/GCTV17-SnailPlaylist>; <http://www.grdc.com.au/GCTV-Slugs>

GRDC 'Back Paddock Guide – Snail identification and control': www.grdc.com.au/Resources/Publications/2011/03/Snail-Identification-and-Control-The-Back-Pocket-Guide

DPIRD 'Identification and control of pest slugs and snails for broadacre crops in WA': www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia

IPM guidelines 'Slugs and snails': <http://ipmguidelinesforgrains.com.au/pests/slugs-and-snails/>

SARDI 'Bash'em, Burn'em, Bait'em': <https://grdc.com.au/uploads/documents/Snails%20BBB.pdf>

6.7 Pest identification and management – spring, harvest and summer

6.7.1 Snails

The three main species of snails that attack WA lupin crops as seedlings and potentially contaminate grain at harvest are:

- » Conical or small pointed snail (*Cochlicella barbara*).



- » White Italian snail (*Theba pisana*)



» Vineyard or common white snail (*Ceruella virgata*)



The small pointed snail is light brown with a conical shell and grows up to 10 mm in length, chewing lupin plant leaves and leaving slime trails.

It is most common in WA's high rainfall areas and control is recommended where numbers reach any more than five per square metre.¹³

The white Italian snail has a white shell, sometimes with broken brown bands in the line of the spiral, and grows up to 24 mm in width.

The vineyard snail has a shell that is up to 20 mm wide with a continuous brown band. Both the white Italian and vineyard snail species feed on crop leaves and control is recommended when numbers exceed five per square metre.

In summer, as conditions begin to dry and temperatures increase, white Italian and vineyard snails move up plant vegetation to avoid water loss.

The small pointed snail may move up vegetation or harbour underneath stubble to retain moisture. Summer rains can trigger short periods of snail activity, but are unlikely to trigger breeding

High levels of snail activity tend to start with the onset of cool, moist conditions in autumn and require only 1 mm of rain to get these pests moving.

¹³ DPIRD website (2016) Identification and control of pest slugs and snails for broadacre crops in Western Australia, www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia

Monitoring

When monitoring lupin crops for snail presence, it is advised to check for irregular pieces chewed off leaves, shredded leaf edges or total defoliation.

Snails tend not to eat seedlings down to ground level, unless the seedling has just emerged.

But lupin plants can not compensate for the damage or loss of cotyledons due to snail damage.

The rule-of-thumb is to monitor numbers on a regular basis and implement control prior to seeding.

Monitoring snail presence and activity in lupin involves:

- January-February – assess stubble management
- March-April – assess numbers for burning and/or baiting
- May to August – assess numbers for baiting, especially along fence lines
- Three to four weeks before harvest – assess numbers for risk of grain contamination.

(SOURCE: DAFWA)¹⁴

Control

Pre-seeding management can assist with controlling snails and tactics include:

- » An even burn of stubbles (can lead to an 80-100 percent kill)
- » Grazing during summer (reduces ground cover)
- » Summer weed control (reduces refuge areas)
- » Using wide points or full-cut discs to 5 cm (can reduce numbers by 60 percent).¹⁵

Baiting is the only option for snail control after the lupin crop has been sown and germination has started.

Multiple bait applications may be required and there are no registered foliar-applied products for snail control in-crop.

Baits are only suitable for snails bigger than seven millimetres in diameter and there is an associated kill rate of around 50 percent when these are applied at 5 kg/ha in areas of the paddock where the pests are active.¹⁶

Spreading baits early can reduce snail numbers, but it may be difficult to obtain good control because snails feed on green plant material as well as decomposing organic matter.

GRDC-funded research has found regular bait re-application is necessary due to field degradation or pest populations not actively feeding, or both.¹⁷

Under testing, commonly used bran-based bait products lasted less than two weeks.

The research showed rainfall not only physically breaks down the bran pellets, it reduces the number of white Italian snails killed, as these were less likely to consume a lethal dose. The project found that mould on products did not influence bait consumption or efficacy.

Researchers found temperature, not UV light, reduces the efficacy of metaldehyde baits. Growers who use metaldehyde products during summer should not expect these to last more than two weeks.

¹⁴ DPIRD website (2016) Identification and control of pest slugs and snails for broadacre crops in Western Australia, www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia

¹⁵ DPIRD website (2016) Identification and control of pest slugs and snails for broadacre crops in Western Australia, www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia

¹⁶ DPIRD website (2016) Identification and control of pest slugs and snails for broadacre crops in Western Australia, www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia

¹⁷ DPIRD website (2016) Identification and control of pest slugs and snails for broadacre crops in Western Australia, www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia

At harvest, if snails remain above control threshold levels of 5 per square metre in lupin crops, it is likely they will contaminate harvested grain.

This can occur if snail management practices were not applied early in the season, or management of the snails was ineffective.

As the harvest progresses, snails migrate up the crop to escape the hot ground and it is ideal in susceptible areas if harvest can coincide with cooler conditions.

Round snails (white Italian and vineyard species) are more likely to be dislodged off crops during harvest. But small pointed snails are often found in sheltered locations, such as between the leaf and stem, are difficult to dislodge and are more likely to be intact in the harvested grain.

Harvester modifications are more effective on round, rather than conical, snails.

Cleaning grain after harvest may remove small pointed snails from the grain. For more information refer to SARDI's 'Bash'em, Burn'em, Bait'em – Integrated snail management in crops and pastures' publication. It can be found here: <https://grdc.com.au/uploads/documents/Snails%20BBB.pdf>

Windrowing, summer weed spraying and fence line weed control can assist in snail management, as can introducing certain beetle species as a biological control measure.

Windrow burning for snail control was found to be effective in 2015 trials in a high rainfall zone, initiated by the GRDC's Albany port zone Regional Cropping Solutions Networks (RCSN) group.¹⁸

This project showed that snails attracted to fallen stubble in the inter-rows could pose an issue for the next crop and burning the windrow could significantly reduce populations.

It is advised that economic and financial implications need to be considered when choosing a management option for snails in WA lupin crops. These include:

- » Understanding the risk of snails being present
- » Gauging potential yield losses associated with snail feeding damage
- » Assessing the costs and benefits of taking preventative action, such as removing a green bridge or destroying stubble
- » Comparing costs, benefits and risks of each management option against doing nothing
- » Considering risk and associated costs or savings of no treatment or delaying treatment
- » Ignoring all previous treatment costs in assessing current management options
- » Undertaking scenario analysis to see what impact changing the variables (such as grain price and seasonal conditions) will have on the economic outcome.

(SOURCE: DAFWA)

A new research project has been initiated by GRDC across the western and southern regions to provide growers with specific localised information for effective timing of snail control.

The focus is on the ecology, behaviours and biology of the most threatening snail and slug species in each region.

In WA, this involves DPIRD researchers monitoring – including with cameras – the small pointed snail at four sites in Albany and Esperance.

They are tracking soil moisture, temperature and humidity data and undertaking laboratory-based snail and slug biology studies.

¹⁸ GRDC Albany port zone Regional Cropping Solutions Networks (RCSN) group project (2015) Hot Topic New Insights to give snails and slugs the slip. <https://grdc.com.au/Media-Centre/Hot-Topics/New-insights-to-give-snails-and-slugs-the-slip/Details>

MORE INFORMATION

GRDC 'Ground Cover TV snail and slug playlists': <http://www.grdc.com.au/GCTV17-SnailPlaylist>; <http://www.grdc.com.au/GCTV-Slugs>

GRDC 'Hot Topic – New insights to give snails and slugs the slip': www.grdc.com.au/Media-Centre/Hot-Topics/New-insights-to-give-snails-and-slugs-the-slip

DPIRD 'Identification and control of pest slugs and snails for broadacre crops in WA': www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia

The goal is to identify the environmental triggers for slug and snail activity and the pest response.

This should lead to better predictions of outbreaks and pave the way for timely and economic control tactics by growers in high risk situations.

At each trial site, there are also investigations into the relationships between the snails/slugs and climate/abiotic factors, such as soil type, amelioration practices and crop rotations.

This is aimed at improving decision-making about the timing and location of on-farm baiting.

6.7.2 Slugs

Lupin can be damaged by the common species of slugs affecting WA broadacre crops. These are the black keeled slug (*Milax gagates*) and the reticulated slug (*Derocerus reticulatum*).

Black keeled slugs are black-brown with a ridge down the back. Reticulated slugs have dark brown mottling and range in colour from light grey to fawn.

Both of these slug species grow to about 25 mm in length and are hermaphrodites, with each of the mating pair able to lay eggs.

Mating usually takes place when favourably moist conditions occur after summer.

Eggs are laid into moist soils in mid-autumn to mid-winter and hatch within two to four weeks. Eggs cannot survive a hot dry summer or lie dormant in the soil. Young slugs become sexually mature at one-year-old.

Slugs tend to inhabit heavier-textured soils and wet areas in WA's high rainfall zones and can be particularly problematic in paddocks where stubbles have been retained or there are rock piles.

They take refuge in soil cracks or under large clods during the day and are active at night, especially when conditions are moist, warm and still.

Damage to lupin crops from slugs includes destruction of seeds at sowing or chewed leaves, shredded leaf edges or eating of whole seedlings to ground level.

Monitoring

Slug activity can be detected by fresh trails of white and clear slime in the morning.

Numbers of about 10 large slugs/square metre may destroy an emerging lupin crop and it is advised that the threshold for control is one or two slugs per square metre.¹⁹

It can be difficult to accurately estimate the population of slugs in a paddock, especially in cracking soils.

A useful method of detection before seeding or crop emergence is to lay lines of slug baits with a rabbit baiter.

In infested areas, slugs are attracted to the freshly turned soil and bait pellets placed in the furrow and soon big numbers will be found dead or dying.

An alternative method to monitor numbers is to place carpet squares or tiles on the soil surface, with pellets underneath. After a few days, count the number of slugs under and around each square.

After sowing and during germination, it is best to examine crops at night for slug activity.

¹⁹ DPIRD website (2016) Identification and control of pest slugs and snails for broadacre crops in Western Australia, www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia

Control

Tips for controlling slugs in WA lupin crops include:

- » Application of baits
- » Baits work best when there is no green material (weeds, crops)
- » Spread when slugs are active after rain
- » Use registered label rates of bait (such as metaldehyde 50g/kg at 5 kg/ha)
- » Use baits in areas where slugs are active
- » Try to avoid late baiting
- » Re-application of baits may be needed (effectiveness is lost after a few days)
- » Burning and tillage can be effective for reticulated slugs (not black keeled slugs).

DPIRD's MyEconomic Tool can help to assess the economics of baiting for slugs and can be found at: <https://www.agric.wa.gov.au/wheat/myeconomic-tool>

MORE INFORMATION

DPIRD 'Lupin root disease':
<https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management>

DPIRD 'Lupin diagnostic tool':
<https://www.agric.wa.gov.au/lupin-diagnostic-tool>

DPIRD-GRDC MyCrop and MyCropApp: <https://grdc.com.au/apps>

DPIRD Diagnostic Laboratory Services (DDLS)-Plant Pathology: <https://www.agric.wa.gov.au/ddls-seed-testing-and-certification>

CropPro: http://www.croppro.com.au/crop_disease_manual/ch10.php

GRDC Fact Sheet 'Plant Parasitic Nematodes': www.grdc.com.au/GRDC-FS-Plant-Parasitic-Nematodes-SW

Australian Pesticides and Veterinary Medicines Association (APVMA) – for registered fungicides and herbicides: <http://apvma.gov.au/>

SARDI PREDICTA® B: http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

Root diseases and nematodes

7.1 Overview

Incidence of root and hypocotyl diseases in Western Australian lupin crops has declined in the past 20 years, but remains an issue for some of the State's growers to manage.

If present, these diseases can reduce lupin stand density, plant vigour and yield.

Root rot occurs in nearly all narrow leaved lupin paddocks but, in most areas, has only a small impact on crop development and major losses are uncommon.

In some paddocks where high levels of root rot occurs, plant establishment and seedling vigour can be affected.

Pleiochaeta setosa and *Rhizoctonia solani* are the major pathogens causing root or hypocotyl infection of lupin.

Risk of hypocotyl rot is higher with legume-pasture rotations and it can be found in most soil types across WA.

When a root disease is present in a crop very little can be done to manage it in that cropping season.

It is therefore advised to correctly identify the cause to enable appropriate management before sowing the next lupin crop.

Correct identification can be made by assessing in-crop symptoms and the root and hypocotyl of affected plants.

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.

Soil testing and monitoring can be done during the growing season through the Department of Primary Industries and Regional Development (DPIRD) – formerly Department of Agriculture and Food Western Australia (DAFWA) – Diagnostic Laboratory Services (DDLS)–Plant Pathology service.

Soil testing can be done year-round through the South Australian Research and Development Institute's (SARDI) PREDICTA® B sampling service. For more information go PREDICTA® B: http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b.

Testing can help correctly diagnose, monitor and manage root and hypocotyl diseases and nematodes in lupin crops.

Growing lupin crops can be an excellent management tool for reducing some nematode species, but are highly susceptible to damage from others.

This reiterates the importance of correct species identification for rotation planning to manage root disease and nematode issues.

i MORE INFORMATION

DPIRD-GRDC MyCrop 'Pleiochaeta root rot': www.agric.wa.gov.au/mycrop/diagnosing-pleiochaeta-root-rot-narrow-leafed-lupins

7.2 Pleiochaeta root rot (*Pleiochaeta setosa*)



Figure 1: *Pleiochaeta* root rot infection on lupin stems.

(SOURCE: GRDC Grain Legume Handbook)

- Rarely leads to major crop losses (except in some situations where lupin is sown after lupin on very infertile sands) in WA
- Minimum tillage and deep ripping can reduce crop effects
- Rotations with non-host crops can reduce spore concentrations in soil.

Pleiochaeta root rot is caused by the fungus *Pleiochaeta setosa* that also causes Brown leaf spot of lupin.

Spores are produced on fallen brown spot-infected leaves and become incorporated into the top few centimetres of soil, where they can persist during summer and across several years.

The spores germinate in the next lupin crop and infect the plant roots of seedlings, causing pleiochaeta root rot.

Spores that have survived on the soil surface can also be splashed upwards by rain droplets and infect leaves and stems, causing Brown leaf spot. This continues the disease cycle.

Pleiochaeta root rot creates lesions on roots, but rarely leads to major crop losses in WA where reduced tillage and extended lupin rotations are used.

Incidence can be higher in paddocks with close lupin rotations and where seeding operations place spores in the root zone.

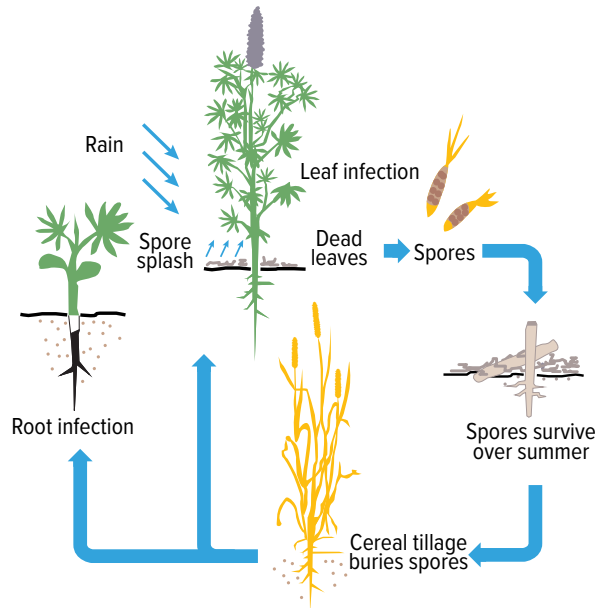
Disease severity and yield impact is determined by the number and distribution of spores in the soil. A high number of spores distributed close to the seed can cause severe disease.

In-crop symptoms of pleiochaeta root rot include wilted, weak or dying seedlings that can be scattered in the paddock or on particular soil types.

Infection produces dark brown lesions on the tap and lateral roots, leading to stripping of the outer layer of the root. In severe cases there is complete rotting of the root.

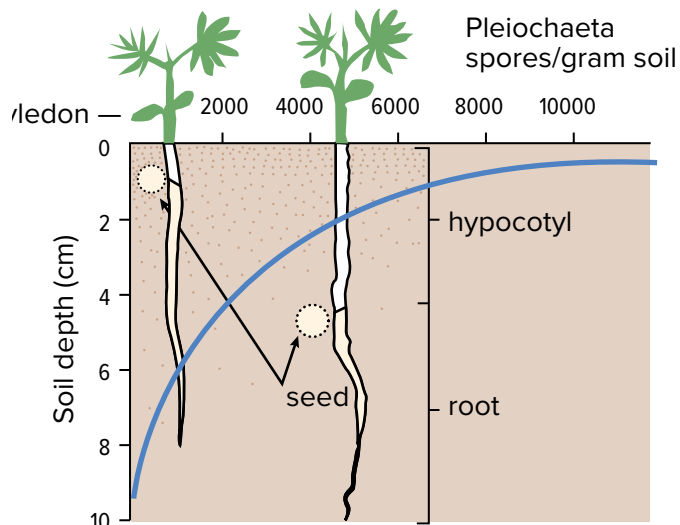
Tap roots are susceptible for six to eight weeks after germination. But new lateral roots are susceptible when they emerge during the season and are often pruned off.

Figure 2: *Pleiochaeta* root rot spore profile in a direct drilled paddock.



(SOURCE: DAFWA)

Figure 3: Infection cycle of *pleiochaeta* root rot.



(SOURCE: DAFWA)

Management of *Pleiochaeta* root rot

- » Use reduced or minimum tillage
- » Deep tillage has been found to suppress disease severity in WA
- » Rotate lupin with non-host crops (such as cereals, canola, pasture)
- » Control Brown leaf spot in preceding lupin crops
- » Fungicide seed treatment with Group 2 actives iprodione or procymidone can provide partial control
- » No fungicide treatments are registered for in-crop use.¹

¹ DPIRD-GRDC (2016) MyCrop diagnostic tool – Diagnosing *pleiochaeta* root rot in narrow-leaved lupins, www.agric.wa.gov.au/mycrop/diagnosing-pleiochaeta-root-rot-narrow-leaved-lupins

i MORE INFORMATION

GRDC Tips and Tactics 'Rhizoctonia – Western Region': www.grdc.com.au/TT-Rhizoctonia

DPIRD-GRDC MyCrop 'Rhizoctonia bare patch': <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-bare-patch-grain-legumes-0>

DPIRD 'Monitoring root diseases': <https://www.agric.wa.gov.au/mycrop/monitoring-root-disease>

GRDC Hot Topic 'Managing Rhizoctonia bare patch in WA': <https://grdc.com.au/Media-Centre/Hot-Topics/Managing-rhizoctonia-bare-patch-in-WA>

Minimum or reduced tillage sowing systems used in WA have been shown to reduce the incorporation of pleiochaeta root rot spores into the rooting zone of the soil profile.

Deeper sowing, such as with spading or mouldboard ploughing, has also been effective in placing emerging crop roots below the spore-laden soil layer.

Rotating lupin with non-host crops, such as cereals, canola or pasture, will typically cut the concentration of soil-borne spores. Controlling Brown leaf spot in preceding lupin crops can also reduce the amount of spores returned to soil.²

Fungicide seed treatments containing Group 2 actives iprodione or procymidone are registered for control of Brown leaf spot in WA lupin crops, but not for pleiochaeta root rot control.

These actives do not give consistent control of pleiochaeta root rot, but trials have found they can provide partial control at registered rates.³ There are no registered fungicide treatments to use in-crop.

7.3 Rhizoctonia bare patch (*Rhizoctonia solani* AG8)

- Occurs on most WA soil types
- Affects lupin and most other crops and pastures grown in WA
- Rotations tend not to break the disease cycle
- All commercial lupin varieties are equally susceptible
- Affected paddocks have distinct patches of stunted or dying crops three to six weeks after sowing
- Yields are severely depleted in patch areas
- Tillage systems affect disease impact
- Seed or in-furrow fungicides are not registered for use in lupin.

Rhizoctonia bare patch is caused by the fungus *Rhizoctonia solani* (AG8) and has a wide plant host range, making rotation with cereals, canola or other pulses mostly ineffective in suppressing disease incidence in lupin crops.

But research in WA and SA has found grass-free canola and pulse crops and pastures can help to reduce inoculum levels in soil to benefit subsequent crops.⁴

Rhizoctonia bare patch is found in most WA grainbelt soil types, especially sandplain areas, and effects all commercially available lupin varieties.

The fungus colonises either living plant tissue or dead organic material, allowing it to survive across years.

After autumn rain, it grows rapidly to infect young seedlings and distinct patches of stunted or dying plants are visible in the crop three to six weeks after sowing.

Long-term trials show rhizoctonia bare patch can also attack crops throughout the growing season.⁵

Yield losses from this root disease in lupin crops are typically proportional to the area of paddocks affected by patches, which can range from 0.5–5 metres in diameter and produce virtually no grain.⁶

2 DPIRD-GRDC (2016) MyCrop diagnostic tool – Diagnosing pleiochaeta root rot in narrow-leaved lupins, www.agric.wa.gov.au/mycrop/diagnosing-pleiochaeta-root-rot-narrow-leaved-lupins

3 DPIRD-GRDC (2016) MyCrop diagnostic tool – Diagnosing pleiochaeta root rot in narrow-leaved lupins, www.agric.wa.gov.au/mycrop/diagnosing-pleiochaeta-root-rot-narrow-leaved-lupins

4 GRDC (2016) Tips and Tactics, Rhizoctonia – Western Region, www.grdc.com.au/TT-Rhizoctonia

5 McKay, A (2006) Fungicide Control of Rhizoctonia Part B Syngenta, SARDI, University of SA, CSIRO Adelaide, DAFWA, http://projects.grdc.com.au/projects.php?action=view_project&project_id=653

6 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing rhizoctonia bare patch in grain legumes, <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-bare-patch-grain-legumes-0>

The tap and lateral roots of affected plants are ‘pinched off’ by dark brown lesions, often having a ‘spear tipped’ appearance. As the season progresses, damaged plants often die.

Management of rhizoctonia bare patch

- » Use deep cultivation at sowing with a narrow tyne 10–15 cm below seed
- » Deep ripping to 25–30 cm immediately prior to sowing can suppress disease
- » Ensure good crop nutrition
- » Avoid herbicide damage to roots
- » No fungicide seed dressing or foliar products are registered for use in lupin
- » Rotation and variety selection will not provide total control.⁷

Deep cultivation at sowing with a narrow tyne 10–15 cm below the seed, or deep ripping to 25–30 cm prior to sowing, are the most effective methods for reducing lupin crop damage caused by rhizoctonia bare patch in WA conditions.⁸

Cultivation with knife-point soil openers can disturb fungal growth in the soil and encourage better root growth, compared to disc sowing systems.

It is advised that sowing at the optimal time, ensuring good crop growth with adequate plant nutrition and avoiding herbicide damage to roots will reduce disease impact.

Research has shown control of the green bridge of weeds and crop volunteers between crops and ensuring good weed control in-crop can also help to reduce crop losses.⁹

Crop rotation and variety selection will not totally control rhizoctonia root rot and there are no registered fungicide seed dressings or foliar actives for use in lupin.

MORE INFORMATION

DPIRD-GRDC MyCrop ‘Rhizoctonia hypocotyl rot’: <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-hypocotyl-rot-narrow-leafed-lupins>

GRDC Tips and Tactics ‘Rhizoctonia – Western Region’ at: www.grdc.com.au/TT-Rhizoctonia

7.4 Rhizoctonia hypocotyl rot, or rhizoctonia root rot (*Rhizoctonia solani*)



Figure 4: *Figure: Rhizoctonia can affect roots of lupin crops in WA, but incidence is relatively low.*

(SOURCE: GRDC)

7 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing rhizoctonia bare patch in grain legumes, <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-bare-patch-grain-legumes-0>

8 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing rhizoctonia bare patch in grain legumes, <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-bare-patch-grain-legumes-0>

9 GRDC (2016) Tips and Tactics, Rhizoctonia – Western Region, www.grdc.com.au/TT-Rhizoctonia

- Affects all lupin varieties and most other crop and pasture legumes grown in WA
- Incidence is relatively low in WA lupin crops
- Affected crops can have poor plant establishment
- Rotation with non-legumes can break disease cycles
- Cultivation practices are ineffective
- Iprodione is registered for suppression.

Rhizoctonia hypocotyl rot, or root rot, is caused by the soil-borne ZG3, ZG4 and ZG6 strains of the fungus *Rhizoctonia solani*.

These pathogens are related to the strains causing rhizoctonia bare patch and effect all lupin varieties – and most other crops and pasture legumes – grown in WA.

Although incidence of rhizoctonia hypocotyl rot in this State is typically relatively low, it can occur in most soil types and reduce plant establishment in affected crops.

The bulk of fungal inoculum is found in the top 5 cm of soil, where it can survive for at least two years in remnant organic matter.

With the onset of opening rains, the fungus grows and infects susceptible seedlings. It is more active with warm soil temperatures and tends to be more prevalent in early sown crops.

Risks of infection are highest in lupin crops following a legume pasture phase as a result of disease build-up and the capacity of fast-germinating pasture seedlings to host infection prior to lupin germinating.

When a root disease such as hypocotyl rot is present, very little can be done to manage it during that cropping season.

It is, therefore, important to correctly identify the cause with soil sampling to allow appropriate management before sowing the next lupin crop.

Above ground symptoms of rhizoctonia hypocotyl rot in WA lupin crops include clumps of poor emergence, uneven and stunted plant growth, wilting or death.

It is the most easily diagnosed of all lupin root diseases, causing reddish-brown sunken lesions on the hypocotyl (below ground portion of the stem).

From emergence until about eight-leaf stage, infected seedlings wilt and die as lesions grow and rot through the hypocotyl.

Infected plants that survive past the eight to 10-leaf stage often remain stunted and tend to be less productive than healthy plants.¹⁰

Management of rhizoctonia hypocotyl rot

- » Avoid lupin rotations after legume pasture
- » Shallower sowing can reduce hypocotyl exposure to the fungus
- » Avoid sowing very early into warm soil in high-risk paddocks
- » Higher sowing rates may compensate for establishment losses
- » Iprodione-based seed dressings are registered for suppression in WA lupin
- » Avoid sowing lupin crops within 24 hours of glyphosate application where a big biomass of weeds have been sprayed on high risk paddocks.¹¹

Crop rotation can be useful to break the rhizoctonia hypocotyl root rot cycle and, in high-risk areas, it may be beneficial to not sow consecutive lupin sequences or lupin after a legume pasture.

Shallower sowing can reduce exposure of the hypocotyl to the fungal inoculum and sowing very early into warm soil in paddocks with known disease risk should be avoided.

¹⁰ DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing rhizoctonia hypocotyl rot in narrow-leaved lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-hypocotyl-rot-narrow-leaved-lupins>

¹¹ DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing rhizoctonia hypocotyl rot in narrow-leaved lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-hypocotyl-rot-narrow-leaved-lupins>

i MORE INFORMATION

DPIRD-GRDC MyCrop 'Eradu patch':
<https://www.agric.wa.gov.au/mycrop/diagnosing-eradu-patch-narrow-leafed-lupins>

Increasing sowing rate by 10–25 percent can help to compensate for establishment losses in high-risk paddocks.¹²

7.5 Eradu patch

- Caused by a thin, binucleate *Rhizoctonia* (TBR)
- Found in WA in the late 1990s
- West midlands and northern agricultural region are most affected
- Causes severely stunted patches in lupin crops, suppressing yields
- Use non-host crops to reduce incidence
- Cultivation, fungicide seed dressing and lupin variety choice are not effective control tactics.

Eradu patch is caused by a thin, unnamed binucleate rhizoctonia (TBR) pathogen that is different to the rhizoctonia bare patch pathogen.

It is less common in WA than rhizoctonia bare patch, but surveys in the past decade have found it present in 8–10 percent of lupin paddocks sampled – particularly in the west midlands and sandplain areas of the northern agricultural region. It has also been found in WA's eastern grainbelt areas.¹³

Eradu patch causes roughly circular patches in narrow leafed lupin crops, with distinct edges that become evident seven to eight weeks after sowing.

It does not affect albus or WA blue lupin, wheat or canola.

Patches in narrow leafed lupin can be 0.5–10 m in diameter and may have a 'doughnut' appearance. Typically, the most severely stunted plants are near the edge and the area may coalesce over time into larger irregular patches.

Light brown-red lesions occur on the tap root of infected plants, often with the outer layer of the root stripped off.

Lateral roots can be pinched off by similar colored lesions.

Management of Eradu patch

- » Rotation with non-host crops or pasture/fallow can reduce patches
- » Cultivation, fungicide seed dressing and lupin variety are ineffective
- » Soil testing is useful to monitor disease presence and level.¹⁴

This fungus survives between seasons in the soil, but two or three years of rotation with non-host crops or pastures can reduce the impact of disease in lupin.

It is advised not to grow a barley crop prior to lupin in susceptible areas, as this can increase disease severity.

Research has found cultivation, fungicide seed dressing and lupin variety are ineffective tools to manage Eradu patch.¹⁵

It can be useful to test the soil for presence and levels of rhizoctonia pathogens through DPIRD's Diagnostic Laboratory Services (DDLs) –Plant Pathology or SARDI's PREDICTA® B service.

12 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing rhizoctonia hypocotyl rot in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-hypocotyl-rot-narrow-leafed-lupins>

13 DPIRD (2016) Lupin root diseases: diagnosis and management – Eradu patch, https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management?page=0%2C2#smartpaging_toc_p2_s0_h3

14 DPIRD (2016) Lupin root diseases: diagnosis and management – Eradu patch, https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management?page=0%2C2#smartpaging_toc_p2_s0_h3

15 DPIRD (2016) Lupin root diseases: diagnosis and management – Eradu patch, https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management?page=0%2C2#smartpaging_toc_p2_s0_h3

i MORE INFORMATION

DPIRD-GRDC MyCrop 'Rhizoctonia hypocotyl rot': <https://www.agric.wa.gov.au/lupin-diagnostic-tool>

GRDC 'Grain Legume Handbook': <https://grdc.com.au/grainlegumehandbook>

7.6 Minor root diseases affecting WA lupin crops

Table 1: A summary of minor root diseases affecting WA lupin crops.¹⁶

Disease	
CHARCOAL ROT (<i>MACROPHOMINA PHASEOLINA</i>)	
Risks	Moisture-stressed crops; survives in soil for multiple years.
Symptoms	Premature senescence of individual plants or patches in-crop. Stems and taproots have ash-grey discoloration (when split open) due to masses of tiny black microsclerotia embedded in the tissue.
Management	Avoid sowing lupin in water-logging prone soils; crop rotations.
Useful resources	https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management
PYTHIUM ROOT ROT	
Risks	Most WA soil types, especially shallow duplex soils and other soils prone to sub-soil saturation.
Symptoms	Roots develop a black rot, hypocotyls can develop water-soaked lesions. Infection can kill emerging seedlings or create weak and stunted plants that wilt at the start of stem elongation.
Management	Avoid sowing lupin in water-logging prone soils; crop rotations.
Useful resources	GRDC Fact Sheet 'Root disease', https://grdc.com.au/uploads/documents/GRDC_FS_Pythium.pdf and DAFWA Lupin disease hub, https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management
ABIOTIC ROOT DAMAGE	
Risks	Various soil structures and properties.
Symptoms	Impermeable hardpans and duplex soils can cause damaged or bent taproots and poorly developed root systems. Waterlogging can result in soft discolored roots, poorly developed root systems and yellowing of plants. Chemical damage from triazine or sulfonylurea herbicides or poor fertiliser placement can cause rotting, pruning or reduced development of roots.
Management	
Useful resources	https://www.agric.wa.gov.au/lupins/lupin-root-diseases-diagnosis-and-management

(SOURCE: DAFWA)

i MORE INFORMATION

GRDC Tips and Tactics ‘Root Lesion Nematodes – Western’: <https://grdc.com.au/Resources/Factsheets/2015/03/Root-Lesion-Nematodes>

GRDC Paddock Practices ‘Managing root lesion nematodes pre-sowing’: <https://grdc.com.au/Media-Centre/Media-News/West/2016/03/Managing-root-lesion-nematodes-presowing>

SARDI PREDICTA® B test results/ Maps: http://pir.sa.gov.au/_data/assets/image/0003/293142/Australia_P_penetrans_map_2016.jpg

7.7 Nematodes



Figure 1: Root lesion nematodes are worm-like microscopic endoparasites that feed on plant roots and can cause patches in crops.

(SOURCE: © Western Australian Agriculture Authority (Department of Agriculture and Food, WA))

- Lupin in the crop rotation can help reduce RLN species *P. neglectus* and *P. quasitereoides* (formerly *P. teres*) in WA soils
- Lupin is very susceptible to *P. penetrans*
- There are no in-crop options to control nematodes
- Crop rotation can help reduce crop damage
- Rotation is influenced by species of nematode present in soil
- Soil and/or plant root testing can identify species and levels of nematodes.

Root lesion nematodes (RLN) are the main nematode species that affect all WA crops, including lupin, and incidence is increasing across the grainbelt.

These worm-like microscopic endoparasites feed on plant roots.

Research indicates they are present in soils covering about 5.74 million hectares of the State’s cropped area.¹⁶

Surveys in recent years have shown RLN populations are at yield-limiting levels in at least 40 percent of cropping paddocks and cause crop losses typically ranging from 15–50 percent.¹⁷

The three main species found in WA are *Pratylenchus neglectus*, *P. quasitereoides* (formerly *P. teres*) and *P. thornei* (not as widespread).

Of the 360-plus PREDICTA® B WA soil samples tested in 2015, 65 percent had *P. neglectus* present and 30 percent had *P. quasitereoides* present.¹⁸

In 2014, testing by DPIRD through its long-term Focus Paddock project found the average number of RLN in infested plant samples it received had increased to about 31,000 RLN per gram root from about 7000 RLN/g root in 2011. Paddocks with the highest numbers were from barley crops infested with *P. quasitereoides*, including one with 55,000 RLN/g root in 2012 and one with 220,000 RLN/g root in 2014.¹⁹

16 GRDC (2015) Tips and Tools – Root lesion nematodes Western Region, www.grdc.com.au/TT-RootLesionNematodes
 17 GRDC (2015) Tips and Tools – Root lesion nematodes Western Region, www.grdc.com.au/TT-RootLesionNematodes
 18 GRDC (2015) Tips and Tools – Root lesion nematodes Western Region, www.grdc.com.au/TT-RootLesionNematodes
 19 DAFWA (2015) PestFax – Root Lesion Nematode levels are increasing, www.agric.wa.gov.au/newsletters/pestfax

Lupin crops are an excellent management tool for helping to reduce *P. neglectus* and *P. quasitereoides* burdens in paddocks, but are very susceptible to damage from *P. penetrans*.

This reiterates the importance of correctly diagnosing the RLN species that are present in paddocks through accredited laboratories.

Correct RLN identification will also assist researchers to characterise nematode distribution in WA and gather further resistance information for crop types and varieties grown in the western region.

Such research is vital because there are no chemicals available to economically control nematodes in broadacre cropping systems.

In-crop symptoms of nematodes are often indistinct, difficult to identify and commonly mistaken for nutrient deficiencies, soil-limiting factors or presence of rhizoctonia.

Big patches, or uneven waves of crop growth, may be evident in paddocks. Up close, plants are often smaller, look chlorotic (yellowing), have reduced tillering, wilt easily and may be dying-off.

If nematodes are present, roots may be stunted, lack lateral roots and may have brown lesions from nematode pruning.

MORE INFORMATION

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

DPIRD Diagnostic Laboratory Services (DDL)–Plant Pathology: <https://www.agric.wa.gov.au/ddls-seed-testing-and-certification>

7.7.1 Testing to identify nematodes

A pre-sowing soil test using PREDICTA® B, offered by accredited advisers through SARDI, can diagnose *P. neglectus* and *P. thornei*, along with Cereal cyst nematode (*Heterodera avenae*). Soil testing and plant root testing for nematode diagnosis in-season can also be carried out by DPIRD's Diagnostic Laboratory Services (DDL)–Plant Pathology (formerly AGWEST Plant Laboratories).

Soil sampling guidelines include:

- » Dig soil to a depth of 0–10 cm
- » Take samples in the crop row, close to roots
- » Sample at six to 12 locations towards the margins of poor growth areas
- » Place all samples in a bucket and mix gently
- » Remove a 500 g sample from the bucket and put in plastic bag
- » Collect a second sample from a healthy crop area
- » Include paddock history and notes on each sample to send to the laboratory.

Plant sampling guidelines include:

- » Collect plants from several locations towards the margins of poor crop growth
- » Use a trowel/shovel to keep root systems intact
- » Retain the soil ball to protect roots in transit to the laboratory.²⁰

²⁰ Collins, S (2014), Know your nematodes and set up a crop defence system in 2015, GRDC, <https://grdc.com.au/Media-Centre/Media-News/West/2014/07/Know-your-nematodes-and-set-up-a-crop-defence-system-in-2014>

7.7.2 Management of nematodes

- » No in-crop options can stop nematode damage
- » Diagnose and monitor species and concentration levels using soil and root testing
- » Avoid growing lupin crops where *P. penetrans* is present
- » Maintain healthy soils and adequate crop nutrition.

Planning crop rotations with resistant varieties or non-host break crops and pastures can help inhibit nematode reproduction/build-up (resistance) and potentially boost crop yields to non-limiting levels under RLN pressure (tolerance).

If there are high or very high RLN levels in a paddock (greater than 10 nematodes/mL of soil or greater than 10,000 nematodes/gram dry root – severity score three and four), it is recommended to grow a moderately resistant (MR) or resistant (R) crop for one to two cropping seasons.²¹

Lupin shows good resistance for *P. neglectus* and *P. quasitereoides* and can be grown where these are present to help break nematode cycles.

But lupin is susceptible to *P. penetrans* and it may be advisable to avoid planting them where this nematode is present.

Maintaining healthy soils and good crop nutrition, especially at crop establishment, can also help to reduce the long-term impact of nematodes on lupin production.

A wide range of parasites and predators of nematodes is found in healthy soils and can provide a degree of protection against plant-parasitic nematodes.

Preliminary results from soil sampling of well-managed, no-tillage and residue-retained cropping systems in WA and SA indicate natural suppressiveness to plant-parasitic nematodes in crop soils may exist and can be improved.²²

21 Collins, S (2014), Know your nematodes and set up a crop defence system in 2015, GRDC, <https://grdc.com.au/Media-Centre/Media-News/West/2014/07/Know-your-nematodes-and-set-up-a-crop-defence-system-in-2014>

22 Collins, S (2014), Know your nematodes and set up a crop defence system in 2015, GRDC, <https://grdc.com.au/Media-Centre/Media-News/West/2014/07/Know-your-nematodes-and-set-up-a-crop-defence-system-in-2014>

MORE INFORMATION

GRDC 'Crop Disease Au App':
<https://grdc.com.au/apps>

GRDC 'Grains Legume Handbook – Chapter 7 Disease Identification and Control': <https://grdc.com.au/grainlegumehandbook>

GRDC 'The current and potential costs from diseases of pulse crops in Australia': <https://grdc.com.au/Resources/Publications/2012/06/The-Current-and-Potential-Costs-from-Diseases-of-Pulse-Crops-in-Australia>

DPIRD 'Lupin diseases': <https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management>

DPIRD-GRDC MyCrop 'Lupin diagnostic tool': <https://www.agric.wa.gov.au/lupin-diagnostic-tool>

DPIRD Diagnostic Laboratory Services (DDLS) —Plant Pathology: <https://www.agric.wa.gov.au/ddls-seed-testing-and-certification>

CropPro: http://www.croppro.com.au/crop_disease_manual/ch10.php

Australian Pesticides and Veterinary Medicine Association (APVMA):
<http://apvma.gov.au/>

Foliar diseases

8.1 Overview

The main fungal and viral diseases affecting lupin foliage, stems and pods in Western Australia are:

- » Anthracnose (*Colletotrichum lupini*)
- » Brown leaf spot (*Pleiochaeta setosa*)
- » Phomopsis stem and pod blight (*Phomopsis leptostromiformis* and *Diaporthe toxica*)
- » Cucumber mosaic virus (CMV)
- » Bean yellow mosaic virus (BYMV)
- » Sclerotinia stem and collar rot (*Sclerotinia sclerotiorum* and *Sclerotinia minor*).

Minor foliar diseases that can affect lupin crops in this State in some years include:

- » Grey leaf spot (*Stemphylium botryosum*)
- » Cladosporium leaf spot (*Cladosporium sp.*)
- » Grey mould (*Botrytis cinerea*)
- » Powdery mildew (*Erysiphe polygoni*).

Yield losses from foliar diseases in WA lupin crops are typically rare on the back of widespread use of fungicide-based seed dressings and foliar fungicides and adoption of wider crop sequences.

But several of the major diseases have potential to cause significant crop losses if left unchecked.

Damage can be prevented or curtailed with an integrated management approach involving variety choice, crop rotations, crop hygiene and targeted seed-based and foliar fungicide use.

Reducing the impact of these diseases will allow WA lupin production levels to be maintained. This, in turn, underpins cereal and canola production by supporting viable and profitable rotations – especially on the State's sandplain soils.

An overview of lupin diseases, symptoms and control tactics is outlined in Table 1¹

¹ CropPro (2016) Identification and management of field crop diseases in Victoria, GRDC and Department of Environment and Primary Industries Victoria, http://www.croppro.com.au/crop_disease_manual/

SECTION 8 LUPIN

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Table 1: Lupin disease guide summary

Disease	Organisms	Symptoms	Occurrence	Inoculum source	Control
Brown leaf spot	<i>Pleiochaeta setosa</i>	Dark spots on leaves and pods, leaves drop off, lesions may girdle stem	Very common but losses usually minor in dry areas, yield loss can be significant in cool damp areas	Spores in soil and lupin trash, rain splash and wind blown rain splash and wind blown rain splash	Fungicide seed dressings, crop rotation, variety selection, early sowing
Pleiochaeta root rot	<i>Pleiochaeta setosa</i>	Browning and rotting of tap and lateral roots, seedling plant death	Serious reduction in lupin plant density and vigour	Spores in soil infecting roots usually at seedling stage, spread also by rain splash	Rotation minimum 4 years between lupin crops, sowing 4–5 cm deep to avoid spore layer, fungicide seed dressings
Rhizoctonia	<i>Rhizoctonia spp.</i>	Bare patches in crop, spear tipped root ends, hypocotyl rot and stain	Can be severe in isolated patches, reduces stand density, favoured by minimum tillage, wet soils and mild conditions	Soil-borne infection on wide host range, survives as fungal fragments in soil and plant debris	Tillage prior and during sowing, rotation has no effect, increased seeding rate
Anthracnose	<i>Colletotrichum lupini</i>	Stems bend over, sticky dark brown lesions in crook of bend, pods and leaves above crook twist and deform, dark lesions with pale centres on leaves, stems and pods	Severe infections can result in complete crop failure	Spores surviving in soil are transported by vehicles, machinery, animals and people, spread in crop by rain splash and wind	Clean seed and machinery, 4 year break between lupin crops, resistant varieties, fungicide seed dressings reduce seedling infection
Cucumber mosaic virus	Virus	All growth after infection is dwarfed, leaflets are yellowed and bunched	Early widespread infection Severely reduces yield. Minor infections prevent use of harvested grain as seed	Seed-borne infection in narrow leaf lupin, aphids transmit the disease within a crop	Sow clean seed, use a seed test, high sowing rates and cereal barriers around crops reduce aphid transmission
Bean yellow mosaic virus	Virus	Brown streaks on stem, shepherd crook, pods blackened and flat, plants wilt and die	Occurs in all lupin growing areas. Can be severe in higher rainfall areas	Seed-borne in albus, aphid spread in crop, many host species	Sow virus free seed. High plant density, cereal barrier

(SOURCE: http://www.croppro.com.au/crop_disease_manual/ch09s06.php)

2 CropPro (2016) Identification and management of field crop diseases in Victoria, GRDC and Department of Environment and Primary Industries Victoria, http://www.croppro.com.au/crop_disease_manual/

i MORE INFORMATION

DPIRD-GRDC MyCrop: <https://www.agric.wa.gov.au/mycrop/diagnosing-anthraxnose-narrow-leafed-lupins>

GRDC 'Grain Legume Handbook – Chapter 7 Disease Identification and Control': <https://grdc.com.au/grainlegumehandbook>

8.2 Anthracnose (*Colletotrichum lupini*)



Figure 2: Anthracnose was a severe disease of lupin crops in WA in the 1990s but incidence is now low.

SOURCE: SARDI

- Risk increases with rainfall, use of infected seed and disease susceptible varieties
- Albus, yellow and WA blue lupin more susceptible than narrow leafed lupin
- All above-ground parts of the plant can be infected
- Yield losses can be up to 50 percent
- Severe infection can lead to plant death
- Variety resistance can reduce the impact from seed-borne infection
- Registered seed dressings and foliar fungicides are effective control measures.

Anthracnose, caused by the fungus *Colletotrichum lupini*, is a highly destructive disease of lupin that can lead to total crop loss in susceptible varieties if not managed. But, typically, it can be eradicated from a paddock, farm or region by using correct rotations and hygiene practices, such as growing non-lupin crops for several years.

In recent years, use of resistant varieties, less sowing of infected seed and registration of foliar fungicides for anthracnose have reduced the impact of this disease in WA, especially in the northern agricultural region.

Continued improved management of anthracnose is expected to enable retention of lupin in crop sequences in disease susceptible areas and help reduce reliance on nitrogen (N) fertilisers and fungicides in cereal phases of the rotation.

The anthracnose pathogen survives on lupin stubbles and can persist for up to two years in (or on) infected seed, which will produce infected seedlings.

These seedlings produce lesions on the root, hypocotyl, cotyledons, leaf petioles or stems, which – in turn – create an abundance of spores.

Spores can be splashed on to surrounding plants by rain and have been shown to travel more than 100 metres to establish the disease in new crops.

Anthracnose-infected seed can cause significant yield losses (up to 50 percent in some trials) in all lupin varieties in WA due to the early establishment of infection.³

The most distinctive symptom of anthracnose in lupin is bending and twisting of stems, with a lesion in the crook of the bend. This is particularly noticeable at flowering.

³ Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

Stem lesions are usually dark brown, with a pale pinkish-orange spore mass in the lesion. The stem can be completely girdled by lesions, or so weakened that it breaks. Both the main stem and lateral branches can be affected and close inspection will often show similar symptoms on leaves.

Pods develop lesions similar to those on stems and are often twisted and distorted. Infections at this stage can result in complete loss of pods or production of infected seed.

Infected seed can appear symptomless, or can be malformed with discoloration, fungal mycelium or pink spores on the seed surface. Seed testing can detect presence and levels of infection.

Management of anthracnose

- » Use resistant varieties in high-risk environments
- » Test seed for presence and levels of infection and use clean seed
- » Thiram (Group M3)-based seed dressing fungicides can reduce disease transmission
- » Destroy or separate WA blue lupin from susceptible varieties
- » Mancozeb active (Group M3) is registered for foliar application
- » Under high disease pressure, foliar sprays are ideally applied at early podding on main stems and first order branches.⁴

The narrow leafed lupin varieties PBA Leeman[®], PBA Jurien[®], PBA Barlock[®], Mandelup[®] and Tanjil[®] are resistant to anthracnose, along with the albus variety Amira[®].

Research has shown anthracnose resistance is most strongly expressed in stem tissue, offering good protection from the impact of seed-borne infection. But resistant varieties can suffer significant yield losses from infection at the flowering and podding stages.⁵

It is recommended that resistant varieties are used in WA's high and medium rainfall zones, especially in the northern agricultural region, to reduce potential yield losses under disease pressure.

In some areas of WA, a degree of seed infection with anthracnose can be tolerated with minimal yield loss. This will depend on variety susceptibility, environment/rainfall zone, use of fungicide seed treatment and proximity of other sources of infection (such as WA blue lupin). To determine the suitability of lupin seed for sowing, it should be tested for the presence and amount of anthracnose infection.⁶

Commercial seed testing can be carried out by DPIRD Diagnostic Laboratory Services (DDLs)—Plant Pathology. For more information see this link: <https://www.agric.wa.gov.au/ddls-seed-testing-and-certification>

If there is zero anthracnose, there is typically no need to apply a seed dressing.

If there is anthracnose, previous research has found fungicide seed dressings with the active ingredient thiram (at a rate of about 1.7–2 Litres/tonne seed) can reduce seed transmission of anthracnose by about 75 percent. Thiram gives poor control of Brown leaf spot, but can be safely used in conjunction with fungicides containing iprodione or procymidone for protection from both diseases.⁷

4 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing anthracnose in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-anthracnose-narrow-leafed-lupins>

5 Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

6 Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

7 Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

Trials carried out from 2001 to 2008 found some foliar fungicide actives could reduce anthracnose infection and lift crop yields in some varieties by up to 0.7 tonnes per hectare.⁸

Mancozeb (Group M3) is now registered for anthracnose control in lupin at rates of 1–2.2 kilograms/ha.

Trials have found the optimum spray timing of foliar fungicide is before infection and at podding on first branches.⁹

Fungicide spraying may be useful when more resistant varieties are not available or when lupin is grown in areas of high disease risk under high disease pressure.

Fungicide spraying can also facilitate the production of higher yielding moderately resistant (MR) varieties (such as Mandelup[®]) in high yield potential, but high disease risk areas (such as high rainfall parts of the northern agricultural region).¹⁰

Agronomic practices such as stubble retention/sowing into standing stubble (except for lupin stubble), avoiding sowing lupin following lupin, controlling volunteer lupin and planting away from any WA blue lupin have been shown to reduce the spread of anthracnose from infected seed.¹¹

i MORE INFORMATION

DPIRD-GRDC MyCrop: <https://www.agric.wa.gov.au/mycrop/diagnosing-brown-spot-narrow-leafed-lupins>

GRDC 'Grains Legume Handbook': <https://grdc.com.au/grainlegumehandbook>

8.3 Brown leaf spot (*Pleiochaeta setosa*)



Figure 3: Brown leaf spot can be widespread but is relatively simple to control.

(SOURCE: GRDC)

- Affects all varieties
- Cotyledons, leaves, stems and pods can be infected
- Control tactics include crop sequencing, resistant varieties, adequate crop nutrition and targeted fungicides
- Application of iprodione (Group 2) or procymidone (Group 2)-based seed dressing fungicides can reduce seedling infection.

Brown leaf spot (*Pleiochaeta setosa*) can be a widespread and costly foliar disease of lupin in WA, but yield losses are now typically rare due to use of full stubble retention and longer lupin sequences in crop rotations.

All species can be affected, including commonly grown narrow leafed varieties Mandelup[®], PBA Barlock[®] and new PBA Jurien[®] and the albus variety Amira[®].

8 Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

9 Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

10 Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

11 Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

Paddocks previously sown to lupin will have *Pleiochaeta* spores in the soil and these can persist for several years, making crop rotation with non-host species an integral control strategy.

Brown leaf spot infection occurs when spores are splashed by rain from the soil on to new lupin plants.

Crop damage can increase at early seedling stage, when plant growth rates are slowed by colder environments, late sowing, poor nutrition, herbicide damage or unfavorable soil type (loam and heavier soils are most prone). Damage at this stage tends to have the biggest impact on grain yield.

Infected cotyledons develop dark brown spots, rapidly become yellow and drop off.

Leaves develop dark brown spots, often become net-like, distorted and small and then drop off prematurely.

Brown flecks may be evident on infected stems and occasionally large brown-black cankers develop that kill the stem above the infection point.

Pods, particularly those set closer to the ground, may be flecked or develop larger brown lesions. Stem and pod infection are usually associated with leaf infection in the upper canopy.

Management of Brown leaf spot

- » Rotate lupin paddocks to non-host crops for at least one year
- » Sow lupin into retained cereal stubble to reduce rain splash of soil-borne spores onto foliage
- » Use agronomic practices that promote seedling vigour and canopy closure – early sowing, adequate nutrition, care in herbicide use and higher seeding rates
- » Select more tolerant narrow leafed lupin varieties
- » Iprodione or procymidone-based seed dressing fungicides are registered, with variable uptake between varieties.¹²

Seed dressing fungicides may be useful in high-risk areas, such as on loamy and heavy soil types and where stubble is not retained, to reduce Brown leaf spot infection in seedlings. But, on sandy soils, if stubble cover is high and there is no paddock history of Brown leaf spot, there is often no need to use a seed dressing.¹³

A potential agronomic issue for Brown leaf spot is weed control, with trials in 2000-04 finding disease damage to leaves could increase with the use of the herbicide simazine (Group C).¹⁴

Glasshouse research in 2004-08 found Mandelup[®] infected with Brown leaf spot could tolerate commonly used post-emergent herbicides (with the actives diflufenican (Group F) and metribuzin (Group C) applied at registered label rates) without affecting plant growth, development or yield. Under low brown leaf spot disease severity, these herbicides might increase disease severity and reduce yields.¹⁵

12 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing brown spot in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-brown-spot-narrow-leafed-lupins>

13 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing brown spot in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-brown-spot-narrow-leafed-lupins>

14 Thomas, G (2004) Advanced management strategies for control of anthracnose and brown spot in lupins, GRDC Final Report, <http://finalreports.grdc.com.au/DAW665>

15 Dhammu, H.S, MacLeod, W.J, Roberts, C, Payne, P.L.M, Antuono, M.F (2008) Interaction of brown leaf spot with post-emergent herbicides in narrow-leafed lupins, DAFWA, <http://www.lupins.org/pdf/conference/2008/Agronomy%20and%20Production/HS%20Dhammu%20W%20MacLeod%20C%20Roberts%20P%20Payne%20and%20M%20Antuono.pdf>

i MORE INFORMATION

DPIRD 'Lupinosis': <https://www.agric.wa.gov.au/livestock-biosecurity/lupinosis-sheep>

DPIRD-GRDC MyCrop: <https://www.agric.wa.gov.au/mycrop/diagnosing-phomopsis-stem-and-pod-blight-narrow-leafed-lupins>

8.4 Phomopsis stem and pod blight (*Phomopsis leptostromiformis*, *Diaporthe toxica*)



Figure 4: *Phomopsis* on lupin stem can typically be seen as purple lesions that bleach with age.

SOURCE: GRDC

- Phomopsis fungus infection can cause lupinosis in livestock
- Stems, leaves, pods and seed can be infected
- Narrow leafed varieties are more susceptible than albus lupin
- Control tactics include more resistant varieties and extending lupin crop sequences.

The major impact of phomopsis stem blight (*Phomopsis leptostromiformis*) and phomopsis pod blight (*Diaporthe toxica*) is production of a mycotoxin (*phomopsin*) as the fungus grows in mature lupin stems.

This can cause livestock sickness or death from lupinosis if grazing of infected stubble is poorly managed.

Crop symptoms of phomopsis usually appear on senescing lupin stems as dark-purplish lesions that bleach with age and contain black fruiting bodies. It can cause plants to lodge.

The fruiting bodies can develop on lupin stubble, often after summer rain, which stimulates growth of the fungus and the production of toxins.

Re-infected seedlings in subsequent crops develop deep-yellow to brown, irregular shaped lesions on stems below the cotyledons. Severe lesions may girdle the stem and kill the plant.

Pod lesions can lead to infected seeds, which appear as either normal or are discolored light yellow to reddish-tan. Web-like grey mould of the fungus may be seen on the seed coat and inside the seed pod.

Management of phomopsis

- » Use more resistant varieties in high-risk areas
- » Extend lupin phases in crop rotation planning
- » Destroy infected crop residues with burning or cultivation
- » Take care when grazing lupin stubbles in high-risk areas
- » Remove stock from lupin stubbles when summer rain is imminent.¹⁶

Narrow leafed lupin tends to be more prone to phomopsis stem and pod blight than albus lupin. But PBA Leeman[®], PBA Jurien[®], PBA Barlock[®] and Mandelup[®] have moderate resistance to both stem and pod infection.

¹⁶ DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing phomopsis stem and pod blight in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-phomopsis-stem-and-pod-blight-narrow-leafed-lupins>

i MORE INFORMATION

DPIRD 'Cucumber mosaic virus': <https://www.agric.wa.gov.au/grains-research-development/cucumber-mosaic-virus-narrow-leafed-lupins>

GRDC 'Fact Sheet Resistance Management Strategy for the Green Peach Aphid in Australian Grains': www.grdc.com.au/GPAResistanceStrategy

GRDC 'Back Pocket Guide Crop Aphids': <https://grdc.com.au/CropAphidsBackPocketGuide>

If weather conditions favor the pathogen, including prolonged rainfall or high humidity in late spring and summer, stubble can develop some toxicity and require care with grazing.

But current commercial varieties do not produce highly toxic stubbles.¹⁷

Increasing breaks between lupin crops in the rotation allows weathering and breakdown of infected stubble, reducing disease inoculum.

8.5 Cucumber mosaic virus (CMV)



Figure 1: Cucumber mosaic virus is seed and aphid-borne and narrow leafed lupin varieties are more susceptible than albus lines.

(SOURCE: GRDC)

- Seed and aphid-borne
- Spread by sowing infected seed and via aphid vectors
- Seed testing for infection is advised
- Neonicotinoid-based insecticide can be used on seed
- Suppressing aphid transmission is a key management tactic.

Infected seed is the biggest source of Cucumber mosaic virus (CMV) incidence in lupin crops across WA. Narrow leafed varieties are more susceptible than albus lines.

A seed infection level of one percent means one plant in every 100 will typically be virus-infected and these will tend to be randomly distributed across the paddock.

Secondary infection occurs by aphids, which acquire the virus from primary infected plants (or weeds, clovers or other pulse crops) and spread it to healthy crops.

Aphid species that spread CMV include Green peach (*Myzus persicae*), Blue green (*Acyrtosiphon kondoi*) and Cowpea (*Aphis craccivora*) aphids that colonise lupin crops – as well as migrants of common non-lupin colonising species, especially Oat (*Rhopalosiphum padi*) and Turnip (*Lipaphis erysime*) aphids.

Areas most at risk from this virus in WA are the high rainfall zones of the northern and central agricultural grainbelt and the south coastal region.

CMV infection causes lupin leaves to become pale, bunched and down-curved with faint mosaic patterns.

It can severely stunt plant growth and the earlier a plant becomes infected, the fewer the pods set, the smaller the size of seed produced and the lower the crop yield.

¹⁷ DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing phomopsis stem and pod blight in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-phomopsis-stem-and-pod-blight-narrow-leafed-lupins>

With late infections, symptoms tend to be restricted to tip leaves.

As shown in Table 2, yield losses from CMV can be as high as 60 percent when all plants in a crop become infected. Losses are greatest when seed with more than one percent infection is sown, aphids arrive early and widespread plant infection occurs.¹⁸

Table 2: Effect of sowing Cucumber mosaic virus (CMV)-infected seed on yield and subsequent seed transmission (data from Western Australian field trials).

Scenario	1	2	3	4
Initial CMV seed infection level	5%	0.5%	5%	0.5%
Aphid arrival	Early	Early	Very late	Very late
Final crop infection	89–95%	34–53%	1–2%	0.1%
Yield loss	36–53%	ns	ns	ns
Harvested CMV seed infection level	12–13%	7%	0.6%	0.1–0.2%

NOTE: ns=yield impact is not statistically significant
(SOURCE: DAFWA)⁹

Management of CMV

- » Grow virus resistant varieties for optimum control
- » Sow tested seed with virus levels less than 0.1–0.5 percent
- » Eliminate weeds and self-sown pulses for aphid and disease control
- » Monitor and control aphids, especially during early crop growth
- » Rotate lupin crops with cereals to break disease cycles
- » If necessary, use seed treatment containing neonicotinoid-based insecticide
- » In-crop insecticides have shown to be ineffective in WA conditions.²⁰

Lupin varieties differ in rates of susceptibility to aphid colonisation and aphid-borne viruses, such as CMV. Further information about resistance ratings to this and other viruses can be found on the DPIRD website at this link: <https://www.agric.wa.gov.au/grains-research-development/management-aphids-western-australian-lupin-crops>²¹

Moderately resistant narrow leafed lupin varieties that are recommended for WA's high rainfall areas include PBA Leeman^ϕ, PBA Jurien^ϕ, PBA Barlock^ϕ, PBA Gunyidi^ϕ, Jenabillup^ϕ, Coromup^ϕ and Mandelup^ϕ.

The new albus variety Amira^ϕ has been found to be tolerant to aphids in WA conditions.

Sowing healthy lupin seed is key to managing CMV in lupin and testing seed is recommended every year.

Seed samples can be sent to commercial testing services, including DPIRD Diagnostic Laboratory Services (DLS)—Plant Pathology, to gauge infection levels.

In low-risk areas, seed with less than 0.5 percent infection can be sown without high risk of yield loss in 'typical' seasons. Seed infection of less than 0.1 percent (shown as

¹⁸ DPIRD (2016) Cucumber mosaic virus in narrow-leafed lupins, <https://www.agric.wa.gov.au/grains-research-development/cucumber-mosaic-virus-narrow-leafed-lupins?page=0%2C1>

¹⁹ DPIRD (2016) Cucumber mosaic virus in narrow-leafed lupins, <https://www.agric.wa.gov.au/grains-research-development/cucumber-mosaic-virus-narrow-leafed-lupins?page=0%2C1>

²⁰ DPIRD (2016) Cucumber mosaic virus in narrow-leafed lupins, <https://www.agric.wa.gov.au/grains-research-development/cucumber-mosaic-virus-narrow-leafed-lupins?page=0%2C1>

²¹ DPIRD (2016) Management of aphids in Western Australian lupin crops, <https://www.agric.wa.gov.au/grains-research-development/management-aphids-western-australian-lupin-crops>

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. But the outcome of sowing seed infected with a range of levels of CMV will vary significantly from year to year and site to site.²²

Sowing seed with a high level of infection, coupled with early arrival of aphids can initiate early epidemics of CMV, with potential to result in high disease incidence, reduced yield and increased infection in harvested seed.

When there is a dry start to the growing season, sowing seed with a high level of infection can result in minimal yield loss and reduction in infection levels in harvested seed. The aphids arrive much later, tending to result in reduced CMV spread.

Seed dressing insecticides containing the active neonicotinoid have been found to help prevent crops from early feeding of aphids and can stop the infection of crops from viruses.

Agronomic practices, such as sowing early into retained stubble, away from neighboring lupin crops, at high seeding rates and using narrow row spacing, can promote early crop canopy coverage and deter aphids from landing.

This can shade over the seed-infected and early infected plants, denying aphids access.

Maximising weed control can also reduce the spread of CMV from lupin to weeds and from weeds back to lupin.

Research has found insecticides applied to crops are ineffective at controlling CMV.²³

i MORE INFORMATION

DPIRD 'Bean yellow mosaic virus': <https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins>

GRDC 'Grains Legume Handbook': <https://grdc.com.au/grainlegumehandbook>

8.6 Bean yellow mosaic virus (BYMV)



Figure 2: *With Bean yellow mosaic virus, the youngest growth of the lupin plant tends to bend over - causing a 'shepherd's crook' appearance.*

(SOURCE: DAFWA)

- Spread by aphid species that colonise lupin
- Can be seed-borne in albus varieties (not narrow leafed lines)
- Crop yield losses can be up to 80 percent if unchecked
- Late summer and early autumn rain can increase spread
- Integrated disease management based on agronomic practices is needed
- Test for and sow virus-free seed.²⁴

22 DPIRD (2016) Cucumber mosaic virus in narrow-leafed lupins, <https://www.agric.wa.gov.au/grains-research-development/cucumber-mosaic-virus-narrow-leafed-lupins?page=0%2C1>

23 DPIRD (2016) Cucumber mosaic virus in narrow-leafed lupins, <https://www.agric.wa.gov.au/grains-research-development/cucumber-mosaic-virus-narrow-leafed-lupins?page=0%2C1>

24 DPIRD (2016) Management of aphids in Western Australian lupin crops, <https://www.agric.wa.gov.au/grains-research-development/management-aphids-western-australian-lupin-crops>

Bean yellow mosaic virus (BYMV) is a serious disease in WA narrow leafed lupin crops if not managed, especially in high rainfall areas of the northern agricultural region.

Disease risk is typically highest in seasons with high summer/autumn rainfall that promote early build-up and migration of aphids.

Crops neighboring clover-based pastures, or containing clover/weeds, are at the greatest risk of infection.

Two strains of BYMV are common in WA. The necrotic strain (BYMV-N) kills the infected plant and the less abundant non-necrotic (BYMV-NN) strain causes stunting without killing the plant.

DPIRD has a comprehensive guide to diagnosing BYMV in WA lupin crops at this link: <https://www.agric.wa.gov.au/mycrop/diagnosing-bean-yellow-mosaic-virus-non-necrotic-narrow-leafed-lupins>²⁵

BYMV-N symptoms include:

- » Occurs before pod set
- » Necrotic streaking of the youngest portion of the shoot
- » This bends over, causing a 'shepherd's crook' appearance
- » The growing tip dies
- » Leaves become pale, wilt and fall off
- » Necrotic streaking and blackening spread across the stem
- » Fast plant death without seed production.²⁶

BYMV-NN symptoms include:

- » Occurs after pod set and is rare
- » Virus is slower to spread
- » Stunted pale plants
- » Deformed and often fleshy leaves
- » Pods blacken and fail to fill while the rest of the plant grows normally (known as black pod syndrome).²⁷

Management of BYMV

- » Promote early crop canopy coverage – sow early, use high seeding rates and narrow row spacing
- » Direct drill into retained stubble – ground cover reduces aphid landing
- » Rotate lupin with non-host crops
- » Ensure good weed control
- » Insecticides applied in-crop are ineffective to control BYMV.²⁸

There is typically only a brief period between initial BWYV symptoms forming in young lupin crops and plant death.

This means incoming aphids can only acquire the virus from infected plants for one to two weeks and infection levels decline rapidly with increasing distance into the crop.

Management of this virus centres on agronomic practices that:

- » Eliminate clover/weed regrowth under lupin crops
- » Avoid sowing adjacent to clover based pastures
- » Deter aphid landing by reducing bare ground exposure.

25 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing Bean yellow mosaic virus – non necrotic in narrow-leafed lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-bean-yellow-mosaic-virus-non-necrotic-narrow-leafed-lupins>

26 DPIRD (2016) Bean Yellow mosaic virus in lupins, <https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins>

27 DPIRD (2016) Bean Yellow mosaic virus in lupins, <https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins>

28 DPIRD (2016) Bean Yellow mosaic virus in lupins, <https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins>

This can be achieved by tactics such as promoting early canopy development, sowing into retained stubbles, using high seeding rates and adopting narrow row spacing.

High plant densities will tend to dilute the proportion of plants infected and increase compensatory growth of healthy plants.

Sowing a non-host crop (for example, a cereal) or a border strip between crops and adjacent pasture can also be effective, as incoming aphids lose the virus when they probe the non-host. This helps to reduce spread into the crop from an external source.²⁹

8.7 Sclerotinia stem and collar rot (*Sclerotinia sclerotiorum*, *Sclerotinia minor*)

MORE INFORMATION

DPIRD 'Sclerotinia': <https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management> or www.agric.wa.gov.au/mycrop/diagnosing-sclerotinia-collar-rot-narrow-leafed-lupins



Figure 3: *Sclerotinia* can affect lupin pods.

(SOURCE: © Western Australian Agriculture Authority (Department of Agriculture and Food, WA))

- Sclerotinia stem rot is an increasing problem in WA lupin crops
- Most common in high rainfall areas
- Typically affects plants after flowering in warm and damp conditions
- Sclerotinia collar rot is less prevalent, but a potential issue in canola-lupin rotations
- Outbreaks are sporadic and yield losses are typically low
- In severe cases, sclerotia become mixed with harvested seed and incurs grain grading costs.

Incidence of sclerotinia stem rot (*Sclerotinia sclerotiorum*) has increased in WA cropping rotations in recent years, mostly as a result of expanded canola plantings.

Lupin crops in high rainfall parts of the northern grainbelt, especially west of Mingenew, were particularly affected by this disease during the wet winter growing seasons of 2013 and 2014.

In cases of sclerotinia collar rot (*Sclerotinia minor*), lesions and fluffy white growth appear on stems just above ground level and contain small black fruiting bodies called sclerotia.

This disease was seen in Mandelup[®] lupin crops in the central grainbelt at the mid-flowering stage in 2016, but it does not typically have a significant effect on crop yields.

Sclerotinia stem rot in lupin occurs during flowering, when ascospores infect petals.

Under constant humid and wet weather, infected petals fall and lodge in branches and infect stems and pods. It can take two or three weeks for in-crop symptoms to be seen.

29 DPIRD (2016) Bean Yellow mosaic virus in lupins, <https://www.agric.wa.gov.au/lupins/bean-yellow-mosaic-virus-lupins>

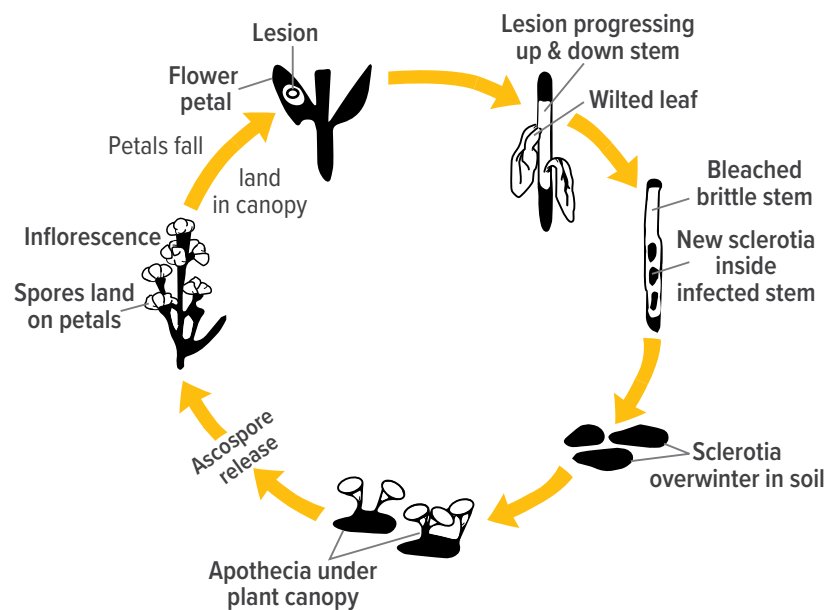
Sclerotinia stem rot symptoms include lesions in the upper half of the main stem, branches and on flowers and pods.

The fungus produces a white cottony-looking growth that girdles the stem, causing the plant parts above the lesion to wilt and die.

Individual pods or complete flower spikes can be completely covered by white fungal growth, which produces hard black sclerotia (of 2–8 mm in diameter).

Stems become bleached looking and infected plants stand out from the rest of the crop. The lifecycle of sclerotinia is illustrated in Figure 3.

Figure 4: *Sclerotinia sclerotiorum* disease cycle.



(SOURCE: DAFWA).³⁰

Lupin crops infected with sclerotinia can have lower yields due to plant death. In severe cases, grain requires grading after harvest to remove sclerotia.

Disease management can be difficult, as sclerotia can survive in the soil for many years.³¹

Management of sclerotinia

- » Rotate lupin crops with non-host species (cereals)
- » Avoid sowing lupin in close rotation with other broadleaf crops, such as canola
- » Control broadleaf weeds during the rotation
- » Foliar fungicides are not registered for sclerotinia in lupin.

Crop rotation with non-host species, such as cereals, and extended breaks between lupin and canola crops can help to break the sclerotinia disease cycle.

There are no foliar fungicides currently registered for treatment of sclerotinia in lupin crops.

³⁰ Thomas, G, Beard, C (2015) Mingenew Irwin Group Presentation, <http://www.mig.org.au/author/zoe/page/3/>

³¹ Thomas, G, Beard, C (2015) Mingenew Irwin Group Presentation, <http://www.mig.org.au/author/zoe/page/3/>

SECTION 8 LUPIN

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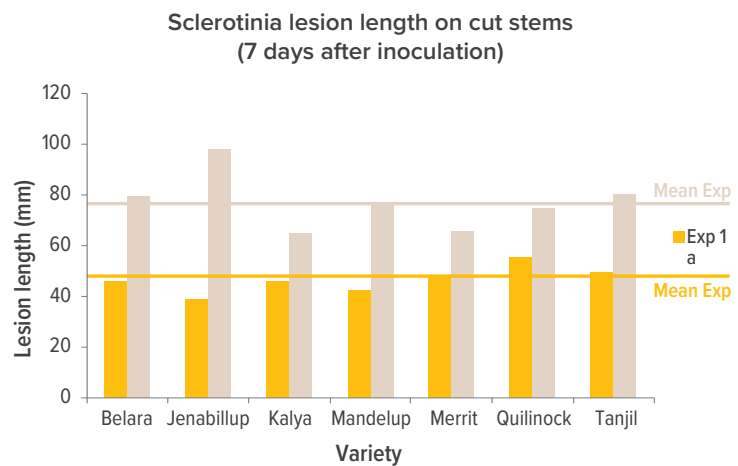
FEEDBACK

Primary risk factors for disease in susceptible areas include:

- » Presence of sclerotia in paddock or neighbouring paddock from previous sclerotinia infection in lupin or canola (or other broadleaf crops or pasture) in the past three or four years
- » Medium-high rainfall areas and/or seasons with wet springs
- » Densely growing crops on heavier soil types that maintain moisture longer and create a humid environment favoured by the pathogen³²

Trials have, to date, found no significant differences in lupin variety resistance to sclerotinia, as shown in Figure 4.³³

Figure 5: Sclerotinia lesion length on cut stems (7 days after inoculation).



(SOURCE: DAFWA)

32 DPIRD-GRDC (2016) MyCrop Diagnostic Tool – Diagnosing sclerotinia collar rot in narrow-leaved lupins, <https://www.agric.wa.gov.au/mycrop/diagnosing-sclerotinia-collar-rot-narrow-leaved-lupins>

33 Thomas, G, Beard, C (2015) Mingenew Irwin Group Presentation, <http://www.miq.org.au/author/zoe/page/3/>

8.8 Minor foliar diseases in WA lupin crops

Disease	Location	Symptoms	Management	Useful resources
Grey leaf spot (<i>Stemphylium botryosum</i>)	Leaves, stems, pods	Brown semi-circular or circular lesions/spots on leaves that can expand and become ash-grey. Brown 'pockmark' lesions on stems and pods. Premature or complete defoliation can occur.	Disease uncommon and rarely economically damaging in WA. Current varieties in WA carry effective genes for resistance.	https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management
Cladosporium leaf spot (<i>Cladosporium sp.</i>)	Leaves, flowers	Dark grey circular spots on flowers and leaves.	Incidence and yield impact in WA rare. No specific control measures, except crop rotations.	https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management
Grey mould (<i>Botrytis cinerea</i>)	Leaves, stems, pods	Lesions on flowers, stems and pods, grey fuzzy mould that may contain sclerotia. May be more common in albus than narrow leafed lupin.	Incidence and yield damage rare, no specific control measures except crop rotations.	https://www.agric.wa.gov.au/mycrop/diagnosing-grey-mould-narrow-leafed-lupins and https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management
Powdery mildew (<i>Erysiphe polygoni</i>)	Leaves, stems, pods	White powdery growth on leaves, stems and pods.	Affects all species but serious crop damage has not been reported in WA. No specific management strategies needed, except crop rotations.	https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

(SOURCE: DAFWA)

MORE INFORMATION

GRDC Fact Sheet 'Pre-harvest herbicide use': www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

GRDC Fact Sheet 'Late season herbicide use': https://grdc.com.au/uploads/documents/GRDC_LateSeasonHerbicideUse_FS.pdf

DAFWA Fact Sheet 'Weed control in mature crops and desiccation': https://www.agric.wa.gov.au/grains/crop-weeds-stop-weed-seed-set?page=0%2C5#smartpaging_toc_p5_s4_h3

DPIRD 'Crop weeds' hub: https://www.agric.wa.gov.au/grains/crop-weeds-stop-weed-seed-set?page=0%2C3#smartpaging_toc_p3_s1_h3

Pulse Australia, Australian Pulse Bulletin 'Desiccation and croptopping in pulses': <http://www.pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping>

Desiccation, crop-topping and green/brown manuring

9.1 Overview

Desiccation and crop-topping involve strategic application of a registered herbicide close to the final maturity of the lupin crop.

These tactics can be used alone or in combination to meet different objectives on individual properties.

Desiccation (typically coupled with windrowing/swathing) terminates crop growth, regardless of the development stage of weeds. The aim is to encourage even ripening of crops and minimal infestations of green weeds for ease of harvest.

It is well suited to Western Australia's southern grainbelt areas prone to late season rainfall and helps to manage risks of weather damage at harvest.

Crop-topping is the application of a non-selective knockdown herbicide near crop maturity and is aimed at preventing seed set in weeds (mainly grasses), controlling in-crop weed escapees and lowering paddock weed seedbanks.

This approach broadens weed management options and strengthens the role of lupin and other pulses in crop rotations for WA farming systems.

For crop-topping, timing is critical and for best results it must be matched to weed seed development – irrespective of the development stage of the crop.

Lupin crops in WA have been found to suffer substantial yield losses if the crop has not reached physiological maturity at or before the timing of crop-topping.

Breeding and variety development by Pulse Breeding Australia (PBA) has produced earlier maturing narrow leafed varieties, such as PBA Leeman[®], PBA Jurien[®], PBA Barlock[®] and PBA Gunyi[®] – and the albus line Amira[®] – that are much better suited to this system than older varieties.

Pulse Australia says, typically, albus lupin tends to mature too late for crop-topping to be effective and desiccation is rarely needed to even-up ripening of these varieties.¹

As with all herbicide use, the Grains Research and Development Corporation (GRDC) advises strict adherence to product label registrations, rates and withholding periods when undertaking desiccation and/or crop-topping in the lupin crop.

Harvest can start as soon as the harvest withholding period has been observed.

Late season herbicide use increases the risks of detectable herbicide residues in harvested grain and it is important to know the maximum residue limits (MRLs) for lupin.

It is recommended to harvest crop-topped lupin as soon as possible (mindful of any withholding periods) if weed seed capture is an objective.

Crop-topping increases the speed at which weeds die-off and drop their seeds on the ground, making capture in chaff carts, bales of straw, windrows or the seed destruction technology important.

¹ Pulse Australia (2016) Australian Pulse Bulletin – Desiccation and croptopping in pulses, <http://www.pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping>

It is advised not to use lupin seed from crop-topped paddocks for planting the following year, as there is a risk of lower vigour.

Using lupin crops for green or brown manuring can be another strategy for reducing weed burdens in WA cropping systems, with the added benefits of improving soil fertility and soil organic matter, but there are significant risks of wind and water erosion from green manuring that would require consideration.

9.2 Windrowing/swathing



Figure 1: Pictures show the pod and seed development of narrow leafed lupin, and embryos from those pods, at various stages in their development. The coloured bars show changes in the colours of the pod, seed and embryo.

(SOURCE: DAFWA)

Windrowing, or swathing, of lupin involves cutting the crop and laying it in a windrow. It is carried out when the seed is close to physiological maturity, before desiccation, to help manage risks of grain shattering and spoilage.

This tactic is suitable for narrow leafed and albus types and also provides benefits of: avoiding grain contamination with green material (such as late germinating weeds); reducing potential grain storage problems (due to high moisture levels in weed seeds); helping to manage crops that are ripening unevenly; and reducing weed seed set as part of a harvest weed seed control program.

Timing the windrowing operation is vital to its success and is based on an assessment of seed maturity in the order of pods (primary to final). This involves checking the cotyledon (kernel) colour, which will often be green for seeds found in pods on the lateral branches and yellow for those found on the main stem.

Typically, windrowing of lupin crops can start when the average moisture content of all seed is 65 percent. This tends to occur at the start of leaf drop, when the stems and leaves of the plant are light green-yellow.

It is recommended to avoid windrowing if seed moisture content falls below 50 percent, as the risk of yield loss through pod drop during the operation and while the crop is in the windrow increases. It is advised to cut the crop 10-20 cm above the ground.

Windrows will typically be ready to harvest about 10-30 days after cutting. Harvester settings are important to minimise potential yield loss from pod drop or shattering.

For albus lupin varieties, it is important to avoid windrowing too early, as immature seeds can shrivel when dry and lead to lower grain quality. For narrow leafed

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varieties, it is advised to avoid cutting crops if there are prolonged dry conditions at harvest, as this can cause higher levels of pod drop. See Chapter 10 for more information about harvesting lupin.

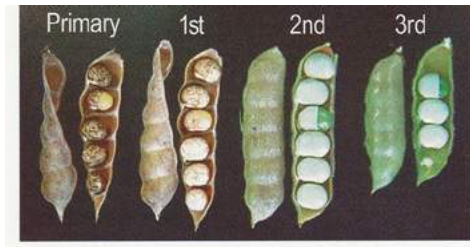


Figure 2: Pod wall, seed coat and cotyledon colour of narrow leaved lupin at the correct stage of maturity to windrow.

(SOURCE: NSWAg Pulse Point)

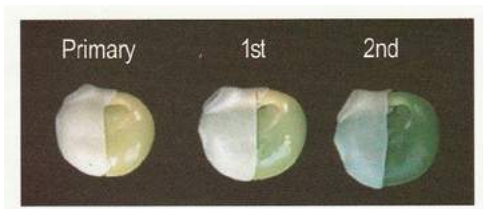


Figure 3: Seed coat and cotyledon colour of albus lupin at the earliest stage at which they should be windrowed.

(SOURCE: NSWAg Pulse Point)

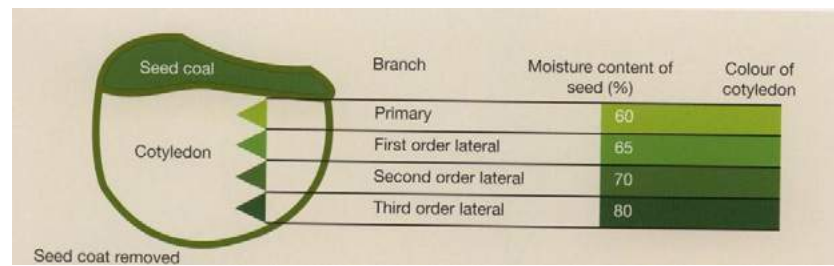


Figure 4: Summary of lupin growth stage and when to undertake windrowing.

(SOURCE: DAFWA)

9.3 Decision-making for desiccation (with windrowing/swathing)

Crop desiccation and windrowing/swathing are predominantly harvest aids. But these practices can provide significant weed management benefits in some conditions and seasons, especially by lowering the weed seedbank.²

The main reasons for using desiccation, with windrowing/swathing, in WA lupin crops include:

- » Accelerate or even-up crop ripening for ease of harvesting
- » Improve harvest speed and efficiency
- » Minimise grain loss from shattering or lodging in prone areas
- » Improve grain quality
- » Reduce risks of weather damage
- » Conserve soil moisture for the next crops
- » Stop seed set in late season weeds
- » Prevent seed set of annual ryegrass (*Lolium rigidum*)
- » Help to manage any herbicide resistance issues.³

9.4 Decision-making for crop-topping

Crop-topping can be a valuable strategy to reduce the weed seedbank to enable early dry sowing in a low-weed-burden paddock the following year, rather than waiting for sufficient rain to germinate weeds for a knockdown herbicide application.

Crop-topping in lupin helps to manage weeds, especially grasses, that are often difficult to control in cereal and canola crops and is a useful part of a longer-term herbicide resistance management plan.

Key reasons for crop-topping WA lupin crops include to:

- » Minimise production of viable weed seeds (especially annual ryegrass and other grasses)
- » Optimise grain yields
- » Even-up crop maturity
- » Help manage any herbicide resistance issues.⁴

2 DPIRD (2016) Crop Weeds: Stop weed seed set – In-crop weed management for seed set control, https://www.agric.wa.gov.au/grains/crop-weeds-stop-weed-seed-set?page=0%2C5#smartpaging_toc_p5_s4_h3

3 DPIRD (2016) Crop Weeds: Stop weed seed set – In-crop weed management for seed set control, https://www.agric.wa.gov.au/grains/crop-weeds-stop-weed-seed-set?page=0%2C5#smartpaging_toc_p5_s4_h3

4 DPIRD (2016) Crop Topping Pulse Crops, <https://www.agric.wa.gov.au/lupins/crop-topping-pulse-crops>

i MORE INFORMATION

GRDC's Fact Sheet 'Pre-harvest herbicide use': www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

DPIRD 'Crop-topping pulse crops': <https://www.agric.wa.gov.au/lupins/crop-topping-pulse-crops>

Pulse Australia Fact Sheet 'Desiccation and crop-topping in pulses': http://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKewjBssbUmMfOAhWDFpQKHW7JDpAQFqgbMAA&url=http%3A%2F%2Fcanfa.com.au%2FLiteratureRetrieve.aspx%3FID%3D104717&usq=AFQjCNExNMc9-H_d1GHCCrAfsjCv2pflfQ

'Maximum residue limits for late-season herbicides': www.pestgenie.com.au and www.apvma.gov.au

Nufarm SprayWise: www.spraywisedecisions.com.au

9.5 Products and timing for desiccation and crop-topping

Desiccating lupin with the Group L herbicide active diquat or crop-topping lupin with the Group L herbicide active paraquat (registered for annual ryegrass only) can be effective to help control some grass weeds in conducive seasons in WA.

It is recommended these tactics are carried out as part of an integrated weed management (IWM) program that might also include cutting crops for hay, green or brown manuring and/or using harvest weed seed control (HWSC) measures.

Desiccation and/or crop-topping is best carried out when lupin plants have lost 80-90 percent of leaves (including all brown leaves still attached to the plant) and grass weed species are at the 'flowering' to 'soft dough' stage.⁵

Early maturing narrow leafed varieties, including PBA Jurien⁶, PBA Barlock⁶, PBA Gunyi⁶ and Mandelup⁶, tend reach this stage up to 10 days before later maturing, older lines, such as Tanjil⁶.

In WA, desiccation and crop-topping success relies on seasonal conditions, especially in high rainfall areas.

If there is a prolonged wet spring, this can extend lupin flowering and podding and annual ryegrass can often develop too quickly (past the ideal stage), before the crop is ready to treat with herbicides.

In the State's northern agricultural region, some growers are successfully crop-topping lupin to help manage annual ryegrass seed set in preparation for dry sowing wheat crops the following year.

The guide to assessing annual ryegrass development stage for desiccation and crop-topping includes:

- » Pull seed off from the middle of the seed head
- » Squeeze the seed between your fingers
- » If there is just sappy liquid – the seed is 'watery ripe'
- » If there is milky, white liquid – this is the 'milk stage'
- » Sap thickness denotes early, middle and late milk stages
- » If there is sap that is sludgy but still soft and like dough – this is the 'dough stage'
- » When there is very limited moisture – this is the 'firm or hard dough stage'
- » If the seed hardly compresses and is a yellow/brown color – this is near 'ripening'
- » After this, it will be too late to get good control.⁶

Research trials in WA have found paraquat can achieve 64-97 percent annual ryegrass control when used for crop-topping at label rates at the annual ryegrass flowering to soft dough stage.⁷

Research has also shown the yields of lupin, and other pulse crops, are typically not reduced if crop-topping is delayed until seeds in the top pods of lupin are 75 percent or more of full size.⁸

But there may need to be a balance between optimal timing for effective annual ryegrass control (which is often earlier) and potential lupin grain yield loss.

5 DPIRD (2016) Crop Topping Pulse Crops, <https://www.agric.wa.gov.au/lupins/crop-topping-pulse-crops>
 6 DPIRD (2016) Crop Topping Pulse Crops, <https://www.agric.wa.gov.au/lupins/crop-topping-pulse-crops>
 7 GRDC Fact Sheet (2015) Pre-harvest Herbicide Use, www.grdc.com.au/GRDC-FS-PreHarvestHerbicide
 8 GRDC Fact Sheet (2015) Pre-harvest Herbicide Use, www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

It is best not to desiccate or crop-top lupin that will have seed retained for subsequent planting, as this has potential to adversely affect seed quality due to uneven ripening.⁹

9.5.1 Paraquat use

WA research and experience has demonstrated that paraquat can be effective for crop-topping when applied later in the season – up to when grass weed seeds have reached soft dough stage.¹⁰

For annual ryegrass, the last seed heads at the bottom of the plant can be emerged and most heads should be at – or just past – flowering and not yet haying-off.

In most grainbelt areas of WA, this is typically in late September and early October.

Guidelines for using paraquat (at 250 grams per litre) on WA lupin crops for crop-topping include:

- » Rates of 400–800 mL/ha
- » Use highest registered herbicide rate
- » Ground application only
- » Minimum spray volume of 30 L water/ha
- » Aim for medium droplets
- » Annual ryegrass should be at or just past flowering
- » Harvest withholding period is seven days after application.¹¹

9.5.2 Diquat use

Diquat is particularly useful for desiccation of lupin and it is recommended to apply as soon as the crop has reached full maturity.

It can accelerate crop drying and reduce seed moisture levels, which reduces grain drying costs, risks of harvesting delays and weather risks at this time of year.

Guidelines for using diquat (at 200 g/L) on WA lupin crops for desiccation include:

- » 2-3 L/ha
- » Application by boomspray or aeroplane
- » Minimum spray volume of 100 L/ha recommended for ground application
- » Spray volume of 30–60 L/ha recommended for aerial application
- » Aim for fine to medium spray quality
- » Flat fan nozzle is preferred on ground
- » Aim to minimise drift from any aerial application
- » Apply when crop has reached full maturity
- » No specified withholding period in WA.¹²

9 DPIRD (2016) Crop Topping Pulse Crops, <https://www.agric.wa.gov.au/lupins/crop-topping-pulse-crops>

10 GRDC Fact Sheet (2015) Pre-harvest Herbicide Use, www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

11 Pulse Australia (2016) Australian Pulse Bulletin – Desiccation and croptopping in pulses, <http://www.pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping>

12 Pulse Australia (2016) Australian Pulse Bulletin – Desiccation and croptopping in pulses, <http://www.pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping>

MORE INFORMATION

DPIRD 'Green manuring': https://www.agric.wa.gov.au/grains/crop-weeds-stop-weed-seed-set?page=0%2C3#smartpaging_toc_p3_s1_h3

DPIRD Carbon Farming Fact Sheet 'Green and brown manuring': <https://www.agric.wa.gov.au/carbon-farming/carbon-farming-fact-sheet-green-and-brown-manuring>

MORE INFORMATION

GRDC Fact Sheet 'Manuring of pulse crops': <https://grdc.com.au/Resources/Factsheets/2013/09/Manuring-of-Pulse-Crops>

GRDC Over the Fence video 'Incorporating a brown manure crop': www.grdc.com.au/OTF-BrownManure

DPIRD 'Brown manuring': https://www.agric.wa.gov.au/grains/crop-weeds-stop-weed-seed-set?page=0%2C3#smartpaging_toc_p3_s1_h3

9.6 Green manuring lupin

This tactic involves growing a crop for the specific purpose of turning it into the soil when green in spring, using cultivation, with the aim of boosting soil organic matter content and reducing weed burdens.

But there is a significant risk of wind and water erosion on green manured paddocks that needs careful consideration.

Green manuring is typically carried out using an offset disc plough. The cultivation aim is to kill weeds and control seed set.

The green manuring process requires good management and timing of cultivation and depends on seasonal conditions. The optimum time to green manure WA lupin crops (in a typical rainfall year) is when they reach early podding stage.¹³

9.7 Brown manuring lupin

In WA, brown manuring is a 'no-till' version of green manuring that uses a non-selective herbicide to desiccate the crop (and weeds) at flowering.

It can be used to help manage weeds and herbicide resistance issues, boost levels of soil nitrogen (N) and organic matter, conserve moisture for subsequent crops, break cereal disease cycles and retain ground cover during summer.

Brown manuring leaves plant residues standing, which can be a preferred option to green manuring on lighter soils that are prone to erosion.

Some of the benefits of adopting brown manuring of lupin crops (especially compared to using a long fallow) may include:

- » Increased crop competition with weeds
- » Prevention of seed set in weeds
- » Less use of knockdown herbicides during the growing season
- » Ability to rotate herbicide modes of action
- » Accumulation of soil N
- » Potential for less fertiliser N use in the next crop
- » Maintenance of ground cover in the growing season and over summer
- » Less soil surface evaporation
- » Water conservation
- » Less risk of wind erosion
- » Better environment for germinating and controlling weeds in summer.¹⁴

Research in the southern region in 2012 found a crop production system that included brown manuring of legumes in the rotation could be as profitable as continuous cropping.¹⁵

This project showed that, even if this system was slightly less profitable, it had considerably fewer production and financial risks due to lower input and operating costs. This is because, typically, crops grown for brown manuring receive minimal fertiliser and fungicides and there is no need for cultivation to turn-in the crop.¹⁶

A long-term trial in WA's central grainbelt, set up in 2003, is investigating the use of brown manuring in the lupin phase of the rotation as part of improved farming systems.

¹³ DPIRD (2016) Crop Weeds: Stop weed seed set – In-crop weed management for seed set control, https://www.agric.wa.gov.au/grains/crop-weeds-stop-weed-seed-set?page=0%2C3#smartpaging_toc_p5_s4_h3

¹⁴ Patterson, R.A (2014) GRDC Grains Research Update Paper 'Brown manure as a farm risk strategy', <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Brown-manure-as-a-farm-risk-strategy-a-whole-farm-perspective>

¹⁵ Patterson, R.A (2014) GRDC Grains Research Update Paper 'Brown manure as a farm risk strategy', <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Brown-manure-as-a-farm-risk-strategy-a-whole-farm-perspective>

¹⁶ Patterson, R.A (2014) GRDC Grains Research Update Paper 'Brown manure as a farm risk strategy', <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Brown-manure-as-a-farm-risk-strategy-a-whole-farm-perspective>

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Preliminary findings from this trial indicate management practices to improve soil fertility (including brown manuring and adding organic matter) are having a positive impact on soil organic carbon levels and potentially soil N. This research is continuing.¹⁷

Researchers nationally have shown brown manuring lupin and other pulses can maximise N fixation by delaying the crop knockdown until it is close to maturity, or as it is reaching maximum dry matter production. This requires effective weed control.

When brown manuring lupin (and other pulse crops), desiccation with registered herbicides should be carried out at – or before – weed seed milky dough stage. This is usually at or before the 80-90 percent pod stage for the lupin crop.

At this stage, the crop is growing at maximum rate – of about 80-100 kilograms of dry matter per day.

If the main aim is to maximise N fixation, the recommendation is to brown manure close to this maximum dry matter production (which will be mostly determined by season and soil type).¹⁸

Other tips and tactics for optimising the value of brown manuring in WA lupin crops include:

- Close analysis of two-year economic benefits in the rotation, especially for sandy soils
- Use tactically in drought years for weed/crop failure risk management
- Avoid or minimise fertiliser application at sowing
- Add phosphorus (P) if soil reserves are low
- Spray crops with a registered knockdown herbicide before viable weed seed set
- Use a double-knock
- Time desiccation on growth stage of weeds, not crops
- Spray before the initiation of lupin pod development.¹⁹

¹⁷ Liebe Group (2007) Liebe Group Soil Biology Trial, Online Farm Trials, www.farmtrials.com.au/trial/10461

¹⁸ Patterson, R.A (2014) GRDC Grains Research Update Paper 'Brown manure as a farm risk strategy', <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Brown-manure-as-a-farm-risk-strategy-a-whole-farm-perspective>

¹⁹ Patterson, R.A (2014) GRDC Grains Research Update Paper 'Brown manure as a farm risk strategy', <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Brown-manure-as-a-farm-risk-strategy-a-whole-farm-perspective>

 MORE INFORMATION

DPIRD 'Lupins': <https://www.agric.wa.gov.au/lupins> and https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4#smartpaging_toc_p4_s2_h2

DPIRD 'Successful lupin harvesting in Western Australia – a Review': https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4#smartpaging_toc_p4_s2_h2

Harvest

10.1 Overview

Shedding (or pod drop) or shattering of mature grain, plant lodging and poor plant flow into machinery have been issues for lupin crop harvesting in Western Australia.

Experience in this State indicates that, to address these problems and lower the risks of yield losses and reduced grain quality, it is advisable to harvest lupin as soon as the crop is ripe.

The best harvesting window is typically within three weeks of crop maturity and as soon as grain moisture content reaches 14 percent. This is the maximum allowable moisture level to meet CBH Group receival standards.

Lupin grain losses can be significantly reduced by harvesting when humidity is high and temperatures are not too hot, especially in northern grainbelt regions.

In cooler southern environments, daytime temperatures are often not warm enough to cause major problems and it may be better to harvest the crop as quickly as possible, rather than swap between lupin and cereals.

Delaying lupin harvesting can lead to brittle grain that is susceptible to cracking and splitting – or incidence of staining, lodging, moulds or disease.

It is advised to take particular care when harvesting lupin grain to use as seed for the next year's crop. Grain harvested late for seed can be of poor quality, with a low percentage of normal seedling germination.

It is recommended to harvest as soon as the crop is mature, setting the harvester drum or rotor speed to a minimum and opening the concave relatively wide.

This tends to reduce damage to the seed embryo and facilitate a high germination percentage after sowing. The seed embryo is very sensitive to impact if it becomes dry and brittle.

Even seed with no visible damage may have a low germination percentage if it suffered a high impact at harvest or during handling post-harvest when its moisture content was low.

Harvest is an ideal time to employ weed seed capture and/or destruction to reduce weed burdens and help manage any herbicide resistance issues.

Tactics include creating and burning harvest windrows, towing chaff carts, using the Bale Direct system that captures chaff and straw material as it exits the harvester, funneling seeds into tramlines or adopting seed destruction technology.

Storing lupin grain for next year's crop also needs close attention, with harvested grain moisture levels of about 13 percent or less ideal for storage.

i MORE INFORMATION

GRDC's 'Grain legume handbook': <https://grdc.com.au/grainlegumehandbook>

New South Wales Department of Primary Industries 'Windrowing lupins': <http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/pulses/lupins/windrowing-lupins>

Using grain silo aeration systems to maintain the average storage temperature below 20°C until the next year's sowing is advised. This can minimise storage insect pest activity and maintain seed quality.

10.2 Harvest timing



Figure 1: *Lupin is best harvested as soon as the crop is ripe and within three weeks of maturity.*

(SOURCE: GRDC)

Risks of plant lodging, pod shattering, pod shedding (or pod drop), grain staining or disease can typically be minimised if lupin is harvested as soon as the crop is ripe and within three weeks of maturity.

Losses of 5-40 percent have been recorded in some WA lupin crops due to shattering of grain when harvest is delayed.¹

A moisture meter is useful to determine when the lupin crop is ready. Harvest is best started as soon as grain moisture content reaches 14 percent (maximum allowable moisture level for CBH Group receival standards).

In some seasons this will occur when plant stems are still pale green, although seeds may have turned yellow inside the seed coat.

In northern grainbelt areas, lupin grain losses can be substantially reduced by harvesting when humidity is high (at night or early morning if necessary) and temperatures are not too hot.

¹ Reithmuller (2008) Successful lupin harvesting in Western Australia – A review. Lupins. Org conference paper, <http://www.lupins.org/pdf/conference/2008/Agronomy%20and%20Production/Glen%20Reithmuller.pdf>

Lupin plants strip well during the night and early morning and, if possible, it is advisable not to harvest in the middle of the day.

In cooler southern environments, daytime temperatures are often not high enough to cause major problems for harvesting.

In these areas, it may be better to harvest the crop as quickly as possible rather than swap between lupin and cereals.

A tin front (also known as closed front) with an extended distance between the knife and auger is ideal for lupin harvesting and harvest is best carried out:

- » As soon as the crop is mature
- » In cooler, rather than hot conditions
- » With the harvester drum or rotor speed set to a minimum
- » With the concave opened relatively wide.

(SOURCE: DAFWA)

10.3 Minimising shattering and pod drop



Figure 2: Swathed and/or windrowed lupin can minimise issues with pod shattering and are typically mature in a similar time to a standing crop.

(SOURCE: GRDC)

Shattering or dropping of lupin pods on entry to the harvester can lead to significant grain losses in WA lupin crops as a result of:

- » Vibration due to cutter bar action
- » Plant on plant contact
- » Reel on crop impact
- » Poor removal of cut material by the auger.

Risks of shattering or pod drop resulting from splitting of mature pods can be reduced by harvesting in high humidity (at night or early morning if necessary) and when temperatures are not too hot. WA grower experience indicates temperatures below 28–30°C are ideal.

Crop-topping is a tool used by some WA growers to help minimise shattering/pod drop by advancing harvest timing and evening-up crop ripening.

This needs to be carried out at the correct crop maturity stage and is not recommended for crops where grain is being retained for planting seed (for more details see Chapter 9 'Desiccation').

Research in New South Wales has found swathing/windrowing lupin, when opportunities arise, can be useful to avoid pod shatter/drop.²

This has a positive spin-off in helping to reduce weed seed set in some years, but can lead to crop yield loss if lupin plant maturity is behind weed seed maturity.

Researchers advise swathing/windrowing when the top pods (those that are the last to mature) are past physiological maturity and in the dry-down phase.

At this stage, the lowest (most mature) pods on the primary or main spike will be close to ripe and have a moisture content of about 40 percent.

Average grain moisture for the whole plant will be about 65 percent and cotyledons will be turning from bright green to yellow (in narrow leafed lupin varieties).

Trials have found it is best not to windrow albus lupin varieties too early, as immature seeds can become shrivelled when dry.

Swathed/windrowed lupin typically mature in a similar timeframe to a standing crop and will be ready to harvest within about 10-30 days (depending on the environment).

But the risk of immature green seeds in the swath has meant most WA growers avoid swathing lupin crops.

Newer narrow leafed lupin varieties PBA Jurien[®], PBA Barlock[®] and PBA Gunyidi[®] have been bred for improved harvest shattering resistance (equal to Coromup[®] and Tanjil[®]).

10.4 Maintaining grain quality

Lupin grain quality can be optimised at harvest by matching timing to correct crop maturity and moisture levels.

Using appropriate machinery can also help to maintain quality by avoiding cracked grain and/or shattering (pod drop).

Grain staining, fungal and disease issues can be managed with correct disease control and fungicide use at the appropriate stage of crop development (see Chapter 8 Foliar diseases for more detail).

Seed coat and cotyledons can be discoloured by crop-topping or premature desiccation in parts of paddocks if ripening is uneven.

To maintain quality of lupin grain being stored for subsequent planting, it is advised to harvest at a seed moisture level of 14 percent or less.

Research has found it is best to store this grain at an average temperature of about 20°C or less. There can be significant loss of grain quality when storage temperatures rise above 30°C.

A wet harvest can lead to issues of staining and weather damage that reduce lupin grain quality for sale or subsequent planting.

MORE INFORMATION

GRDC Fact Sheet 'Retaining seed': https://grdc.com.au/uploads/documents/GRDC_FS_RetainingSeed2.pdf

² New South Wales Department of Primary Industries 'Windrowing lupins': <http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/pulses/lupins/windrowing-lupins>

Rain at harvest can also result in lupin seed that produces low seedling vigour at the next planting. It is advisable to harvest seed crops early and before any rain, if possible, to minimise the risk of seed quality issues.

Weather damaged seed grain is more susceptible to poor germination, low vigour and degradation during storage and handling.

Symptoms include loose and wrinkled seed coat, staining or fully germinated seed.

It can be worth testing any retained seed for germination, vigour and presence of any seed-borne disease.

It is recommended to avoid excessive handling of lupin grain, as it is easily damaged by machinery and augers during harvesting (shattering/pod drop), grading (cracking) and the next sowing.

MORE INFORMATION

DAFWA 'Successful lupin harvesting in Western Australia – a review':
https://www.agric.wa.gov.au/lupins/lupin-essentials-%E2%80%93-growing-successful-lupin-crop?page=0%2C4#smartpaging_toc_p4_s2_h2

10.5 Machinery configuration

To minimise losses from pods shattering or dropping on entry to the harvester and to avoid damaging lupin grain, recommendations include:

- » Reducing the peripheral speed of the harvester drum or rotor to a maximum 12 metres per second (down from 20 to 30 m/s for cereal harvest)
- » Using double density knife guards
- » Extending knife to auger distance
- » Using draper fronts and air reels.³

Harvesters will have a range of drum or rotor diameters, each with different speeds.

Check the configuration so that the correct rotational speed can be used for lupin crops.

Other general rules-of-thumb for lupin harvester settings include incorporating:

- » Slow reel speeds
- » High spiral clearance
- » Thresher speeds of 400-600 rpm
- » Concave clearance of 10-30 mm
- » High fan speed
- » Top sieve of 32 mm
- » Bottom sieve of 16 mm.

(SOURCE: Pulse Australia)

Using closed (comb) fronts

Most losses from closed fronts are typically caused by the plant impacting with the spiral.

To avoid the risk of this occurring, it is advisable to ensure the height between the point of cut on the stem and the top of the crop is less than the distance between the knife and centre point of the spiral.

Consequently, it is recommended to use extended fronts – where the gap between the knife and the auger (spiral) is extended.

Losses may also be reduced by increasing the finger gap to 16 mm. Remove a finger as necessary.

When readjusting the front for wheat or barley crop harvesting, it is best to check the knife is timed so that it stops behind a finger.

³ Reithmuller (2008) Successful lupin harvesting in Western Australia – A review. Lupins. Org conference paper, <http://www.lupins.org/conference/2008/Agronomy%20and%20Production/Glen%20Reithmuller.pdf>

Using open fronts

Open fronts have typically replaced closed fronts in the WA grainbelt due to increased harvesting flexibility for a wide range of crops.

There are generally two types of header fronts used in WA: conventional auger/tin fronts; and the more recent draper/belt fronts.

Extended tin fronts are ideal for harvesting lupin crops, but these are often narrower than draper fronts (typically 9 m for tin front and 12 m or more for draper front) and often not as good as draper fronts for harvesting cereal crops.

Many WA lupin growers own a tin front specifically for harvesting lupin and switch to a draper front for other crops.

Draper fronts can cause high lupin grain losses, particularly when harvesting very short lupin crops.

To reduce lupin grain losses and optimise grain quality when using conventional auger or tin fronts, recommendations include:

- » Fit double density (quad) knife guards
- » Avoid a double density knife with double density knife guards
- » Use a finger or tyne reel
- » Extend the table and knife forward by up to 300 mm
- » Fit Lupin Breakers® on the table auger
- » Use a large capacity auger that has 1.5 pitches per rotation
- » Fit a reduced diameter auger barrel with larger flights than the conventional auger barrel
- » Raise the auger to give a bigger gap between the table and the auger flighting
- » Alter the retractable finger timing when fully retracted at the two o'clock position (viewed from driver's left-hand end)
- » Replace standard reels with air reels (on light crops), either manifold or full-width fan work well depending on power available
- » Use a Vibra-Mat® that oscillates with the knife.

(Source: DAFWA 'Producing Lupins' Bulletin)

When using draper or belt fronts, harvesting losses can be minimised by:

- » Fitting double density finger/knife guards and air reels
- » Raising the knife to be level with the belts to aid flow
- » Using a finger or tyne reel
- » Moving forward augers that are over the feeder house
- » Fitting Lupin Breakers® to this small auger.

Using swathing/windrowing

Lupin crops can be swathed and laid in a windrow when grain is close to physiological maturity.

At this point, the grain is fully formed and no longer increases in weight but is too moist to harvest with a conventional harvester.

The crop dries out in the windrow and is harvested between 10 and 30 days later.

Success of this strategy is highly dependent on swathing at the correct time, which is when the average moisture content of all seed on the lupin plant is about 65 percent.

This typically occurs at the start of leaf drop, when plant stems and leaves are light green to yellow and cotyledons of the seed are usually green (which may vary depending on where the seeds are held on the plant).

Swathing is generally not recommended if seed moisture content is less than 50 percent. This can reduce yields through pod drop during the swathing operation and as the plants dry in the windrow.

For swathing, the crop is best cut 10 to 20 cm above the ground.

A large width of crop compacted into a small, dense windrow reduces the loss of yield through pod drop.

Harvesting of windrows requires careful management, as most grain yield losses tend to occur during this operation.

It can be advisable if considering swathing lupin in WA to use a pick-up front for windrows to increase harvest speed and reduce grain losses.

There can be a risk of downgraded grain due to immature green seeds in the sample, which is likely to occur when swathing is carried out too early and before all lupin seeds are mature.

In WA, in some situations, swathing lupin crops can be beneficial. This includes when there is a need to harvest very short lupin crops.

Direct harvesting of short, low yielding lupin risks high grain losses due to shedding as the header front contacts the lupin crop.

Some growers using swathing in this situation will aim to concentrate two swaths into one swath to improve pick-up of the swaths.

But many WA growers avoid swathing lupin due to the high risk of immature green seeds being present and potential yield losses.

MORE INFORMATION

WeedSmart '10-point plan': <http://www.weedsmart.org.au/10-point-plan/capture-weed-seeds-at-harvest/>

GRDC 'Integrated Weed Management Manual': <http://www.weedsmart.org.au/bulletin-board/integrated-weed-management-manual/>

GRDC Hot Topic 'Integrated weed management in WA': <https://grdc.com.au/Media-Centre/Hot-Topics/Integrated-Weed-Management-in-WA>

10.6 Harvest weed seed capture and control



Figure 3: Chaff carts are a practical and proven way to capture a high proportion of weed seeds at harvest.

(SOURCE: GRDC)

A major biological weakness of most WA cropping weeds is that most of their seed does not shatter before harvest, providing a good opportunity for removal.

Common harvest weed seed control (HWSC) tactics that can be used in WA lupin crops to lower the weed seed bank and help manage herbicide resistance issues include:

- » Collecting chaff in chaff carts
- » Using the Bale Direct system to collect straw and chaff as it exits the harvester
- » Depositing chaff on narrow windrows for burning or livestock grazing the next autumn
- » Using seed destruction technology to pulverise chaff fraction as it leaves the harvester
- » Diverting the chaff onto permanent tramlines (in controlled traffic farming systems) or into narrow rows.

The main benefits of HWSC systems are preventing inputs to the weed seedbank and removing seed from weeds that have survived earlier herbicide applications.

This reduces the selection pressure for herbicide resistance evolution.

Australian Herbicide Resistance Initiative (AHRI) research at 24 sites across southern Australia during the 2010 and 2011 harvests found windrow burning, chaff cart and seed destruction systems were equally effective at removing annual ryegrass (*Lolium rigidum*) seed from cropping paddocks.

Each of these HWSC methods led to an average 60 percent reduction in annual ryegrass germination the following year.

All HWSC systems are limited by how many weed seeds enter the front of the harvester.

The key to success is optimising the set-up and operation of the harvester.

In 2014 trials in south eastern Australia, five harvesters were used and settings were not changed from what growers were using across the remainder of the paddock.

Cab settings of the five harvesters used in the 2015 trials were adjusted to maximise the efficiency of an attached iHSD, although no physical changes were made to concaves or grates.

Adjusting these settings helped to ensure that grain and weed seeds were moved out of the concave and onto the sieves.

Key findings from these trials included:

- » An average 47 percent of annual ryegrass seed was lost in the straw fraction in 2014
- » The range of loss of this seed in straw fraction in 2014 was 28-70 percent
- » Only 3.4 percent of annual ryegrass seed on average was lost in the straw fraction in 2015
- » The range of loss of this seed in straw fraction in 2015 was 1-9 percent
- » Increasing harvester speed did not affect weed seed capture.

The research showed that by ensuring harvesters are not travelling too fast, growers can potentially prevent grain losses worth as much as \$20 per hectare (in wheat crops).

i MORE INFORMATION

GRDC ‘Grain legume handbook’
Chapter 9: <https://grdc.com.au/grainlegumehandbook>

Soil Quality.org.au ‘Fact sheets – Benefits of retaining stubble – WA’: <http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble>

10.7 Stubble management



Figure 4: *Stubble retention, such as pictured here sown with new lupin crop, maintains ground cover, reduces erosion risks and helps conserve valuable soil moisture and nutrients.*

(SOURCE: GRDC)

Historically in WA, the practice of removing crop stubbles by burning was widespread for ease of sowing the following year and to break cereal disease cycles.

In recent years, there has been a shift to alternative stubble management tactics, including mulching, slashing or leaving residue partially or wholly standing.

The primary agronomic purposes of stubble retention are to reduce runoff and soil loss from wind or water erosion, conserve soil moisture and nutrients for subsequent crops, protect young seedlings and lower the risks of rain splash of Brown leaf spot spores.

Retaining or partially retaining standing lupin stubble at a level of about two tonnes per hectare generally provides about 50 percent ground cover and research indicates this can significantly reduce soil losses compared to areas where stubbles have been burned.⁴

⁴ Soil Quality.org.au ‘Fact sheets – Benefits of retaining stubble – WA’: <http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble>

Stubble from lupin crops will also provide slow-release nitrogen (N) to the soil and has an added advantage of typically containing about 150-250 kilograms of grain per hectare after harvest.

This makes lupin stubbles an attractive grazing source for sheep and cattle during the summer months.

Levels of fallen grain in lupin crop residue can often provide enough feed for one to three months of sheep grazing, depending on: stocking rate; any development of lupinosis; risk of wind erosion; and rainfall.

Lupinosis is a disease that affects livestock that eat dead lupin stems colonised by the fungus *Diaporthe toxica* (formerly known as *Phomopsis leptostromiformis*).

The fungus produces toxins – called *phomopsins* – in warm moist conditions and when consumed by livestock these can damage the liver and can result in the animal becoming jaundiced.

10.8 Grain storage



Figure 5: Quality control is the key focus of on-farm storage for lupin grain to be used for seed the following year.

(SOURCE: GRDC)

Lupin grain with high germination and vigour test results can remain viable in storage for up to three years if seed moisture levels are maintained below 13 percent.

Storage life will depend on storage temperature and incidence of stored grain pests and diseases.

It is recommended to dry lupin seed that has been harvested at a moisture content above 15 percent before it is stored (especially in unaerated silos).

As a general rule, the moisture content of lupin grain to be stored and sown the next year should be 13 percent or less.

The optimal storage temperature for lupin grain is an average of 20°C and below 25°C.

It is advisable not to store lupin seed contaminated with green pods from wild radish weeds.

MORE INFORMATION

GRDC 'Stored Grain' information hub: www.storedgrain.com.au

GRDC Back Pocket Guide 'Stored grain pests identification': <http://storedgrain.com.au/stored-grain-pests-identification-the-back-pocket-guide-2011/>

GRDC Hot Topic 'Using aeration cooling for stored grain in WA': <https://grdc.com.au/Media-Centre/Hot-Topics/Using-aeration-cooling-for-stored-grain-in-Western-Australia>

High temperatures can volatilise toxic compounds from the radish pod that can kill the lupin seed. This process can happen in a matter of days, so temporary storage can be damaging.

Other tips for optimal storage of lupin grain include:

- » Using white/light silos to reflect heat
- » Using silos with capacity greater than 75 t that remain cooler than smaller silos
- » Monitoring stored grain pest activity
- » Monitoring grain quality and temperature
- » Consider aeration cooling systems for stored grain insect and pest control and maintaining grain quality.

Loading and out-loading of lupin grain from storage should be done with care.

Silos are designed to withstand uniform downward and outward forces and, to keep these forces uniform, silos must only be loaded from the central top hatch.

Loading from the side top hatch will unbalance the lateral forces on opposite sides of the silo, which could distort the shell of the silo and place extreme pressure on the side holding the high side of the stack.

The same principles apply when out-loading and the silo should only be emptied from the bottom central opening.

It is best to not use the 'bagging-off' chute unless the silo is designed to withstand off-centre loads.

The physical characteristics of lupin grains means higher pressures are exerted on silo walls than with some other grains.

When transferred to the lower sections of the silo wall, these forces may cause crimping or pleating of the walls (seen in elevated and flat bottom silos). For this reason, it is advised not to store lupin grain in older type silos with thin walls.

 MORE INFORMATION

DPIRD 'Western Australian lupin industry': <https://www.agric.wa.gov.au/grains-research-development/western-australian-lupin-industry>

Pulse Australia 'Australian Pulse Bulletin': <http://pulseaus.com.au/growing-pulses/publications/marketing-pulses>

Pulse Australia 'Australian Pulse Standards 2016/2017': http://pulseaus.com.au/storage/app/media/markets/20160801_Pulse-Standards.pdf

Pulse Australia 'Pulse Traders': <http://pulseaus.com.au/marketing/pulse-traders>

Pulse Australia 'Australian CropForecast': http://pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf

AgriFutures Australia (formerly Rural Industries Research & Development Corporation) 'Lupin': <http://www.agrifutures.com.au/farm-diversity/lupin/>

Grain markets

11.1 Overview

The bulk of Western Australia's total annual production of narrow leaved lupin grain is exported, predominantly for use as animal feed, to key markets in the European Union, Japan and Korea.

The remainder is retained on-farm for use as stock feed or planting seed, or traded to domestic buyers.

There has been growing international interest in the use of lupin grain, processed to flour or flakes, for human consumption. This is because it is uniquely high in protein (30–40 percent) and dietary fibre (30 percent) and low in starch, meaning it has a low glycaemic index (GI).

Lupin flour and/or flakes are included in a range of bakery, meat and beverage products in Australia, Europe and some other countries, but these remain mostly niche markets.

Pulse Australia data shows that in 2014–15, Australia exported about 250,000 tonnes of lupin grain (November–October) from national production of 565,000 t in 2014 (including about 384,000 t in WA).

This was well down from the decade's peak annual lupin grain exports of about 650,000 t in 2011–12, when total WA production was about 679,000 t and national production was about 901,000 t¹

WA is effectively the only Australian exporter of lupin grain, which generally competes with soybean in the international market for vegetable-based proteins for livestock industries.

Lupin has consistently been valued at 70–75 percent of the price of soybean meal in global markets.

Since 2007–08, export prices for lupin grain have fluctuated from about \$225 per tonne in 2011–12 to about \$350 per tonne in 2014–15. This has correlated with high and low Australian and WA production levels, respectively.²

The price of imported vegetable protein, such as soybean meal, canola meal or palm kernel meal, strongly influences the lupin export price, according to Pulse Australia.

Soybean meal is usually in high supply and can be sourced all year round, enabling forward ordering and regular shipments.

Annual average prices for narrow leaved lupin on the domestic market in the past 15 years (Fremantle Free-in-store) have fluctuated from a low of just under \$150/t in 1999 to a high of just under \$350/t in 2015. Estimates for the 2016 crop are about \$320/t.³

1 Pulse Australia 'Australian Pulse Crop Forecast' (June, 2016): http://www.pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf

2 Pulse Australia 'Australian Pulse Crop Forecast' (June, 2016): http://www.pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf

3 Pulse Australia 'Australian Pulse Crop Forecast' (June, 2016): http://www.pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf

11.2 Export destinations

In recent years, the Republic of South Korea has been the major international buyer of WA narrow leafed lupin grain. This country has a high capacity dehulling plant and uses hulls in animal feed and kernels for pig feed rations.

Other, smaller, export markets for WA narrow leafed lupin include the Netherlands, Egypt, Japan and Spain.

Most of these markets use lupin grain for animal feed, although small human food markets are developing for lupin flour and flakes.

The main export market for albus lupin is Egypt, where the grain is consumed as a snack food.

This is a limited market, which has had a total import requirement of about 50,000 t annually in recent years.

Over-production of albus lupin in Australia can exceed Egyptian market requirements and flatten demand accordingly.

Despite similar nutritive value, albus lupin is not as readily accepted into domestic feed markets as Australian narrow leafed lupin.

This is possibly driven by the historically higher price for this grain in export markets, where demand often out-strips production.

11.3 Domestic markets

If growing lupin for sale on the domestic market, marketing decisions should factor in Australian seasonal conditions, as these will strongly influence farm gate price.

Drought years tend to increase domestic demand for lupin, which can push prices above those achieved in export markets.

Pulse Australia maintains a list of pulse traders who deal in export and domestic markets. Smaller buyers and traders can be found in local networks.

Pulse Australia recommends growers consider the following factors when making lupin marketing decisions:

- » Estimates of domestic lupin production
- » Estimates of domestic availability, type and quality of protein feeds (including green pasture)
- » On-farm storage capacity to enable marketing across the year
- » World price and availability of soybean meal
- » Demand for on-farm use by graziers as a fodder grain (especially in droughts).⁴

MORE INFORMATION

Pulse Australia 'Pulse traders':
<http://pulseaus.com.au/marketing/pulse-traders>

⁴ Pulse Australia 'Australian Pulse Crop Forecast' (June, 2016): http://www.pulseaus.com.au/storage/app/media/industry/20160613_AU-pulse-crop-forecast.pdf

 MORE INFORMATION

Lupin Foods Australia:
<http://www.lupinfoods.com.au/>

Irwin Valley: <https://glutenfreeshop.com.au/irwin-valley-lupin-flour-500g.html>

University of Western Australia
'A little lupin improves the bread of life': <http://www.news.uwa.edu.au/201106133641/research/little-lupin-improves-bread-life>

DPIRD 'Lupin Markets': <https://www.agric.wa.gov.au/grains-research-development/western-australian-lupin-industry>

11.4 Human consumption markets

Lupin grain has a unique combination of high protein, high fibre, low oil and virtually no starch.

Less than 4 percent of global lupin production is consumed as human food, but it is estimated about 500,000 t of food containing lupin ingredients is consumed each year in the European Union alone.⁵

This is mainly through inclusion of low rates of lupin flour used in wheat-based bakery products.

Research has found that consuming foods enriched with flour or flakes from Australian narrow leafed lupin can provide a feeling of fullness, resulting in people eating less and consuming fewer kilojoules.⁶

Other potential health benefits of eating lupin include a more balanced blood glucose level, a lowering of cholesterol and improved bowel health.

Lupin-enriched foods have the potential to provide additional health benefits, including:

- » Better satiety (appetite suppression) and energy balance
- » Glycemic control – reduced blood glucose and insulin response
- » Improved blood lipids
- » Provision of soluble fibre
- » Lowering of total cholesterol
- » No adverse effect on HDL cholesterol.⁷

A lupin grain processing plant was operated in WA until 2016 by Lupin Foods Australia. Its closure has reduced the capacity of lupin processing in this State.

Several other companies process lupin for food or feed in WA and nationally, including Irwin Valley.

It is advised that any expansion of this local capacity could boost the potential for WA lupin grain to be used in the large Indonesian tempeh market (in place of soybeans).

This could help to increase lupin prices and stimulate increased production of this grain legume in WA and across southern Australia.

5 DPIRD website (2016) 'Western Australian lupin industry': <https://www.agric.wa.gov.au/grains-research-development/western-australian-lupin-industry>

6 Regina Belski (2011) 'A little lupin improves the bread of life'. University of Western Australia, <http://www.news.uwa.edu.au/201106133641/research/little-lupin-improves-bread-life>

7 Regina Belski (2011) 'A little lupin improves the bread of life'. University of Western Australia, <http://www.news.uwa.edu.au/201106133641/research/little-lupin-improves-bread-life>

i MORE INFORMATION

Pulse Australia 'Australian Pulse Standards 2016-17': http://pulseaus.com.au/storage/app/media/markets/20160801_Pulse-Standards.pdf

11.5 Grain specifications

Pulse Australia, in consultation with the Australian pulse industry, compiles standards for all pulse grains to ensure the best quality is provided to customers on world markets.

Some export markets may have additional specific standards and/or specific quarantine restrictions regarding weed seeds, disease and contaminant levels.

Compliance with these guidelines is typically the responsibility of individual commodity traders and these are communicated to growers directly.

Prices for lupin have been relatively high in recent years, based on strong domestic demand.

In some years, there has been a price advantage from storing lupin on-farm, or in a warehouse facility, to market after harvest.

The Pulse Australia publication 'Australian Pulse Standards 2016-17' lists a range of domestic and export market receival standards and defect classifications for lupin grain.

These standards cover aspects such as seed purity, moisture, mould, colour, foreign material and snails and apply to all species of lupin (and other pulses), unless specified.

In WA, grain receival standards exist specifically for lupin at receivals and include: standard farmer-dressed; WA farmer-dressed: export standard farmer-dressed; and export standard machine-dressed. Details can be found at this link http://pulseaus.com.au/storage/app/media/markets/20160801_Pulse-Standards.pdf

Farmer-dressed pulses are taken to processor or vendor facilities for classing and storage. Pulses that meet receival standards for human consumption are accepted for delivery and further cleaning and storage.

Pulses that do not meet the minimum receival standards for human consumption may be supplied for export in the farmer-dressed state or may be supplied for stock feed.

Pulses meeting the minimum standards for human consumption undergo a process known as machine dressing that removes most of the impurities and foreign matter that might remain in the produce.

Machine-dressed pulses can be sold directly to the public for consumption. The machine-dressed product may be supplied to distributors for sale domestically or for export, or for further processing, such as sorting, grading, splitting or canning.

11.6 On-farm factors influencing lupin deliveries and marketing

There are a range of agronomic, pest and disease factors that can influence lupin delivery options, marketing strategies and returns to growers.

These include, but are not restricted to, Native budworm (*Helicoverpa punctigera*), Lucerne seed web moth (*Etiella*), snails, Phomopsis stem blight (*Phomopsis leptostromiformis*) and Phomopsis pod blight (*Diaporthe toxica*), weed seed contamination and harvester settings (leading to cracked grain).

Pests

Native budworm (*Helicoverpa punctigera*)

This pest can affect returns at harvest from direct lupin grain weight loss (due to seeds being wholly or partly eaten) or downgraded grain quality. Native budworm can cause unacceptable levels of chewed grain or fungal infections introduced via caterpillar entry into seed pods, especially in albus lupin crops (and other pulses with big grains). The percentage of broken, chewed and defective seed found in grain samples affects the final price of pulse crops, particularly those marketed for human consumption.⁸

⁸ DAFWA (2017) Management and economic thresholds for native budworm, https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm?page=0%2C1#smartpaging_toc_p1_s2_h2

Lucerne seed web moth (*Etiella*)

Incidence and abundance of Lucerne seed web moth varies by season and location. Severe infestations can result in a loss of lupin yield and quality at harvest. Moth flights commonly occur in mid to late September and often coincide with early pod development in pulse crops. Larvae burrow into pods within 24 hours of hatching and feed on the pods and seeds, remaining until the entire content has been eaten. Frass is left in the pod and adjacent pods may be webbed together as larvae move between pods. Seeds are typically only partially eaten, often with characteristic pin-hole damage. Damage is difficult to grade out and the resulting unattractive appearance reduces seed quality.⁹

Snails

Snails can not only clog up and damage harvesting machinery, causing delays, but also have potential to contaminate grain. In the 'Farmer Dressed' and 'Export Farmer Dressed' markets, the receival standard is a maximum of one snail per 200g sample. In the 'Export Machine Dressed' standards, there is a nil tolerance of snails.¹⁰

Disease

Phomopsis stem blight (*Phomopsis leptostromiformis*) and phomopsis pod blight (*Diaporthe toxica*)

This fungal disease can infect all parts of the lupin plant, but is more commonly seen on dry stems at maturity, pods and (in some cases) seed. The fungus produces a toxin that can cause lupinosis in grazing livestock, but also has potential to downgrade grain in the market. On pods, large, irregular reddish-tan lesions appear, often covered with powdery grey mould. Infected seeds either appear normal or are discoloured light yellow to reddish-tan. Web-like grey mould may be seen on the seed coat and inside the seed pod. Small black fungal spots on lupin trash may give the stems a flecked appearance.¹¹

Weed seed contamination

Weed seed tolerances in delivered lupin grain vary between States and Territories under respective legislation. All persons trading pulses are advised to refer to relevant legislation for appropriate Weed Seed Standards to ensure compliance. There is no tolerance of toxic and/or noxious weed seeds that are prohibited by State laws against inclusion in stockfeed. There are standards for small foreign seeds, which are those that are not the pulse being sampled.¹²

Harvester settings

As outlined in Chapter 10, lupin crops should be harvested as soon as they are ripe. If lupin are not harvested within three weeks of maturity, shedding may cause significant yield losses. Losses of 5-40 percent can occur as pods shatter entering the header. Vibration due to cutter bar action, plant on plant, reel on crop impact and poor removal of cut material by the auger all cause shattering and grain loss. Grain loss can be reduced by harvesting in high humidity, at night if necessary, to minimise pod shattering. Avoid reaping in extreme heat. Finger reels are less aggressive than bat reels and cause fewer pod losses. Double acting cutter bars reduce cutter bar vibration losses. Four finger guards with open second fingers also reduce vibrations.¹³

9 GRDC-Queensland Government, IPM Guidelines for Grains, <http://ipmguidelinesforgrains.com.au/wp-content/uploads/Etiella.pdf>

10 Pulse Australia, (1 August 2016) Australian Pulse Standards 2016/17, Lupins, *Angustifolius* minimum receival standards farmer dressed parameter requirements, http://pulseaus.com.au/storage/app/media/markets/20160801_Pulse-Standards.pdf

11 GRDC Grains Legume Handbook, 2008, <https://grdc.com.au/resources-and-publications/all-publications/publications/2008/03/2008-grains-legume-handbook>

12 Pulse Australia, (1 August 2016) Australian Pulse Standards 2016/17, Lupins, *Angustifolius* minimum receival standards farmer dressed parameter requirements, http://pulseaus.com.au/storage/app/media/markets/20160801_Pulse-Standards.pdf

13 Reference: GRDC Grains Legume Handbook, 2008, <https://grdc.com.au/resources-and-publications/all-publications/publications/2008/03/2008-grains-legume-handbook>

MORE INFORMATION

DPIRD 'Western Australian lupin industry': <https://www.agric.wa.gov.au/grains-research-development/western-australian-lupin-industry>

GRDC 'Grain Legume Hand book – Pulses as Stockfeed': <https://grdc.com.au/uploads/documents/10%20Pulses%20as%20Stockfeed.pdf>

Lupins.org 'Resources – feed and food': <http://www.lupins.org/feed/>

DPIRD 'Lupinosis in sheep': <https://www.agric.wa.gov.au/livestock-biosecurity/lupinosis-sheep>

MORE INFORMATION

DPIRD 'Supplementing feeding and feed budgeting of sheep': https://www.agric.wa.gov.au/autumn/supplementary-feeding-and-feed-budgeting-sheep?page=0%2C1#smartpaging_toc_p1_s2_h3

DPIRD 'Supplementary feeding calculator': <https://www.agric.wa.gov.au/feeding-nutrition/supplementary-feeding-calculator-pregnant-and-lactating-ewes>

Lupin as a feed source

12.1 Overview

It is estimated about half of Western Australia's lupin grain production is retained on-farm for use as stock feed and planting seed.

Lupin growers also trade grain on the domestic and export markets to supply the stock feed manufacturing sector. The bulk of this is used for feed destined for ruminants (cows and sheep), followed by monogastrics (pigs and poultry).

There is growing interest in lupin grain for use by the WA dairy sector and a small, but increasing, use in aquaculture industries.

Lupin grain is a highly suitable feed for ruminants, as it is a relatively low-cost, high-protein and high-energy product with virtually no starch.

Composition of carbohydrates in lupin seed make it more suited to fermentative digestion in ruminants than to monogastric intestinal hydrolysis.

This means the energy value of lupin for ruminants is roughly equivalent to that of cereals, but for pigs, lupin grain is discounted by the proportion of energy recovered.

For poultry, the energy value of lupin is significantly compromised by the lack of any effective fermentative function within the avian stomach.

12.2 On-farm uses for lupin

12.2.1 Supplementary feeding

Lupin grain is a nutritional and economic source of on-farm supplementary livestock feed in WA's mixed farming systems.

It is high in crude protein (28–34 percent), digestible protein (13–15 percent) and metabolisable energy (ME), with low starch levels, and is a particularly safe feed option for ruminants.

Ruminant animals can readily digest all components of narrow leafed lupin grain, as resident microbial populations provide the enzymes required to degrade the soluble and insoluble complex carbohydrates.

Content of lignin, the compound that can limit fibre digestion, is very low (at less than 1 percent) and the overall digestibility of lupin grain is about 90 percent.

This high digestibility, combined with moderate oil content, results in an ME value of about 13 megajoules per kilogram, which is higher than in cereal grains.

A big advantage of lupin grain is that ruminants typically do not require an introduction period to avoid the potential problem of acidosis. This is due to its low starch level and relatively high digestible crude fibre content.

Lupin grains are also large, highly palatable and easy to broadcast into thick cereal stubbles.

The grain is an ideal option for finishing sheep for a particular market, such as live export or sale of prime lambs.

A high energy and medium protein ration, such as a lupin-cereal mix, is best when grain protein content is 12.5 percent or more for weaners/adults (weighing more than 20 kilograms) and 15 percent for weaners weighing less than 20 kg.¹

The general rule-of-thumb for on-farm supplementary feed rations is three parts cereal to one part lupin grain.

Lupin can be included in drought rations of breeding sheep at levels of at least 10 percent of the ration (depending on the relative price of lupin and cereal grain).²

Lupin grain does not cause grain poisoning, which means it can also be conveniently used to condition stock to cereal-based rations by changing gradually from lupin to cereals.

12.2.2 Improving sheep reproduction

Research in WA has shown that feeding lupin grain as a paddock supplement to rams at a rate of 750 grams per head per day for eight weeks before joining can improve testicle size and condition and encourage maximum fertility.³

Feeding lupin grain to ewes as a paddock supplement at a rate of 400–500 g/head/day for one week before and after joining has been found in some trials to significantly increase lamb marking percentages (especially if ewes are less than condition score three).⁴

The nutrition of pregnant ewes influences lamb birth weight and survival and feeding levels should depend on: the condition of the ewes; stage of pregnancy; proportion of twins; and the amount and quality of dry paddock feed.

12.2.3 Sheep weaner performance

Feeding lupin grain to weaners can help maintain or increase weight without a significant setback following weaning.

Lupin and other grain supplements are used to achieve a target growth rate of about 50 g/head/day, and up to 150–250 g/head/day if destined for slaughter markets. Feed budgeting tools are available.

12.2.4 Milk and cattle production

Using lupin grain in feed rations has been shown to increase the milk production of beef and dairy cattle.

It can be more valuable to include in the diet than cereal grain because it tends to not lower the fat content of milk (as high levels of cereal grains may do).

As a result of improved nutrition (and increased milk production) from lupin grain supplementation, there can also be a marked boost in the growth of suckling calves.

Lupin grain is an efficient supplement for finishing cattle, which typically grow more quickly on these rations than those containing cereal grain concentrates. As with sheep, a good rule-of-thumb is to use a ration mix of three parts cereals to one part lupin.

Feeding lupin in a trough, or on the ground, at a rate of 3 kg/head/day will maintain cattle weight on dry summer pastures in WA.

1 DPIRD (2016) Supplementing feeding and feed budgeting of sheep, https://www.agric.wa.gov.au/autumn/supplementary-feeding-and-feed-budgeting-sheep?page=0%2C1#smartpaging_toc_p1_s2_h3

2 DPIRD (2016) Supplementing feeding and feed budgeting of sheep, https://www.agric.wa.gov.au/autumn/supplementary-feeding-and-feed-budgeting-sheep?page=0%2C1#smartpaging_toc_p1_s2_h3

3 DPIRD (2016), Feeding rates for rams pre-joining, https://www.agric.wa.gov.au/management-reproduction/joining-%E2%80%93-setting-potential-your-ewe-flock?page=0%2C1#smartpaging_toc_p1_s2_h3

4 DPIRD (2016), Flushing or feeding lupins prior to joining, https://www.agric.wa.gov.au/management-reproduction/joining-%E2%80%93-setting-potential-your-ewe-flock?page=0%2C2#smartpaging_toc_p2_s3_h3

12.2.5 Pigs and poultry

Non-ruminant animals, such as pigs and poultry, lack the enzymes required to digest complex carbohydrates in the stomach and small intestine.

Unless there is fermentation in the lower tract (for example, in pigs), the digestibility of energy from lupin grain in these species is much lower than in ruminants.

Even where substantial fermentation in the lower tract does occur, the net energy yield from lupin is lower than for grains that are largely digested in the upper tract. There is evidence for pigs that this value may also be influenced by other components in the diet.

For pigs and poultry, it is advised that narrow leafed lupin grain is supplemented with free lysine and methionine – or combined with a protein source rich in these amino acids.

Commercial pig producers have successfully used up to 30 percent whole lupin grain in feed rations.

It is often not economical to de-hull lupin grain to enhance feeding value and this can lead to discounts of 1–1.5 MJ in formulations by stock feed manufacturers because so much of the carbohydrate is fermented in the hind gut and the energy is not fully available to animals.

Poultry rations typically contain less than 10 percent lupin grains and often this is in the form of kernels due to problems of sticky, or wet, droppings.

Albus lupin has a higher protein and crude fat content than narrow leafed lupin, with higher energy value and similar digestibility for this market.

12.3 Aquaculture uses

Demand for alternative protein sources to fishmeal in the aquaculture industry has stimulated interest in the potential of lupin grains in WA.

Major international feed companies are known to routinely use lupin kernel meal in aquaculture feed formulations.

Researchers have investigated the potential for lupin grain to be used as a plant-based feed source in aquaculture operations.

It found lupin was particularly useful for fish and fish diets because of the highly digestible level of protein, good levels of digestible energy and highly digestible phosphorus.⁵

Lupin grain also strengthened extruded pellets, leading to less dust and breakages.

The salmonid and prawn feed markets could potentially use value-added lupin products in this State.

Researchers have investigated the nutritional impact of removing the seed coat (de-hulling) of the lupin grain.

They used narrow leafed and albus varieties in whole-grain and kernel meal form to feed to silver perch (*Bidyanus didyanus*), an omnivorous species.

This research showed clear nutritional advantages from de-hulling lupin grains, irrespective of species used, in digestibility of dry matter, nitrogen (N) and energy.⁶

5 Brett D. Glencross, BSc(Hons) MSc PhD, DAFWA (2001), Feeding lupins to fish: A review of the nutritional and biological value of lupins in aquaculture feeds, http://www.fish.wa.gov.au/Documents/occasional_publications/fop031.pdf

6 Brett D. Glencross, BSc(Hons) MSc PhD, DAFWA (2001), Feeding lupins to fish: A review of the nutritional and biological value of lupins in aquaculture feeds, http://www.fish.wa.gov.au/Documents/occasional_publications/fop031.pdf

 **MORE INFORMATION**

DPIRD 'Grazing stubbles and dry pasture': <https://www.agric.wa.gov.au/autumn/grazing-stubbles-and-dry-pasture?page=0%2C2>

DPIRD 'Lupinosis in sheep': <https://www.agric.wa.gov.au/livestock-biosecurity/lupinosis-sheep>

12.4 Grazing lupin stubbles

Lupin grain losses during harvesting in WA often exceed 150 kg/ha, which increases the value of this crop stubble for grazing livestock.

The amount of grain on the ground will largely determine the paddock's stock carrying capacity because it has a high digestibility and a high proportion is used by the animal.

Sheep and beef cattle tend to do better on lupin stubbles than on cereal stubbles in WA because of the high energy value and protein content of the grain.

A low starch content also minimises the risk of digestive upsets (such as lactic acidosis), common when stock are introduced to cereal stubbles.

It is typically safe to graze lupin stubbles until there is about 50 kg/ha of grain on the ground, or the level of groundcover is 50 percent or less (whichever comes first).⁷

To measure the level of grain on the ground in lupin stubbles, recommendations are:

- » Place a tenth of a square metre quadrat on the ground
- » Count the number of grains inside
- » Include grains in whole pods
- » Sample at 30 random sites across the paddock
- » Eight seeds per quadrat equates to about 100 kg/ha of grain in the paddock.

Grazing sheep will typically consume more than 250 g/head/day of lupin grain in stubble paddocks.⁸

For example, if there is 200 kg/ha of lupin grain remaining after harvest, sheep grazing at a rate of 10 dry sheep equivalent (DSE)/ha will eat down to 50 kg/ha within eight weeks (if grazing is uniform).

Research in WA has found lupin stubbles can maintain or increase the weight and condition of all classes of sheep and are a particularly good summer feed source for weaners.

Weaners and small cattle can gain up to 200 g/head/day when grazing lupin stubbles, but typical weight gains are about 100–150 g/head/day.

Lupin stubbles are also useful to use when joining sheep, as the good quality feed increases ovulation rates in ewes.

Typically, six weeks is the maximum length of sheep grazing of lupin stubbles in WA.

Development of lupinosis, caused by toxins produced by the fungus *Diaporthe toxica* (formerly known as *Phomopsis leptostromiformis*), is a risk.

This fungus mainly grows on the lupin plant stem and ingesting too much can cause damage to the animal's liver, leading to loss of appetite, poor production and, potentially, death.

It also results in significant animal production losses, without any other obvious symptoms.

Management is the key to preventing stock losses from lupinosis and close monitoring for early detection of affected animals in flocks or herds is important.

⁷ DPIRD (2016) Grazing stubbles and dry pastures, https://www.agric.wa.gov.au/autumn/grazing-stubbles-and-dry-pasture?page=0%2C2#smartpaging_toc_p2_s2_h2

⁸ DPIRD (2016) Grazing stubbles and dry pastures, https://www.agric.wa.gov.au/autumn/grazing-stubbles-and-dry-pasture?page=0%2C2#smartpaging_toc_p2_s2_h2

Other tactics to reduce the risk of this condition in WA lupin stubble paddocks include:

- » Grazing order – lupin stubbles before cereal stubbles
- » Pre-feeding lupin grain before stubble grazing
- » Ensuring water availability close to stubble
- » Assessing paddocks for grain on ground and presence of fungus on plants
- » Feed budgeting
- » Husbandry procedures – don't introduce sheep with pink-eye
- » Maintaining stocking rates at or below 15 DSE/ha
- » Not using stubbles for pregnant ewes
- » Removing stock from stubbles when rain is imminent.

(SOURCE: DAFWA)

Treating sheep affected by lupinosis:

- » Immediately remove from lupin stubble
- » Place in a small paddock with shade and water
- » Provide a small amount of oats in the best-quality grassy paddock, or good quality oaten hay
- » Avoid paddocks with green plants
- » Do not feed lupin or feed blocks
- » Reduce all stress
- » Restore appetite
- » Avoid dehydration.

(SOURCE: DAFWA)

12.5 Lupin for stock feed manufacture

The bulk of WA lupin used by manufacturers for compound feed rations is destined for the ruminant (cows and sheep) market, followed by pigs and poultry.

There is also increasing demand for lupin grain from the domestic dairy sector and from a small aquaculture market.

The nutrient content of WA lupin grain, in protein, amino acid, energy and mineral levels, has been well established and is widely accepted by stock feed manufacturers.

Lupin grain stacks up well compared to alternative grain options for seed weight, seed protein, seed oil and alkaloids and has significant advantages in being able to be used as a whole grain in rations.

The thick seed coat (hull or testa) makes up about 30 percent of seed weight for yellow lupin, 25 percent for narrow leafed lupin and 15 per cent for albus lupin.

This is considerably higher than for most domesticated grain species and is mostly comprised of cellulose and hemicellulose. This means it is important to consider the composition and nutritional value of the cotyledons (kernel). There is virtually no starch in any grain produced from WA lupin species, which is in marked contrast to crops such as field pea and chickpea, which can have 50-70 percent of the cotyledon weight as starch.

Lupin is an economical source of protein and energy for livestock feed formulations, typically containing 28–42 percent crude protein (depending on variety).

The nutrient and energy value of major lupin species is outlined in Table 1.

Table 1: Nutrient and energy values of the three lupin species

Nutrient and energy values of the three lupin species (whole seed)			
	<i>L. angustifolius</i>	<i>L. albus</i>	<i>L. luteus</i>
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) The Chemical Composition and Nutritive Value of Australian Pulses. Grains Research and Development Corporation, Canberra Australia)

Other advantages of lupin grain compared to alternative feed grains include:

- » High concentrated levels of both protein and energy
- » Free from major anti-nutritional factors (such as trypsin inhibitors)
- » No requirement for heat treatment
- » Ease of handling and storage due to a robust seed coat
- » Readily accepted by livestock.

(SOURCE: Lupins.org)

i MORE INFORMATION

CSIRO 'A review of the nutritional value of lupins for dairy cows':
<http://www.publish.csiro.au/paper/AR06109.htm>

12.6 Dairy – an emerging market for WA lupin grain

There is an emerging domestic market for lupin grain as a feed source from dairy producers in WA, mainly on the back of its cost effectiveness and high protein and energy value.

Other advantages include low acidosis risk (due to a lack of starch) and low levels of anti-nutritional factors, such as trypsin inhibitor, tannins, lignin and lectins.

Research in 2007 found the benefits of using lupin grain in dairy cow feed formulations included:

- » Increased average milk production of 0.53 kg milk/kg dry matter of lupin (compared to straight pasture/cereal hay diets)
- » No negative effects on milk yield, fat content or protein.⁹

But there was some reduction in milk protein concentration and variable effects on fat concentration.

This project found substitution of cereal grains with an equivalent weight of lupin grains in dairy concentrate rations typically resulted in increased milk yield, fat, and protein – and a higher fat concentration.

Researchers attributed the higher yield responses to the higher ME content of lupin, compared to cereal grains.

Although, contribution from a potentially lower incidence of rumen lactic acidosis could not be discounted.

The project found feeding albus lupin to dairy cows significantly shifted the fatty acid profile of milk towards Australia's national dietary guidelines for improved cardiovascular health in humans.¹⁰

9 C. L. White, V. E. Staines, M. H. Staines, (2007), A review of the nutritional value of lupins for dairy cows. CSIRO, <http://www.publish.csiro.au/paper/AR06109.htm>

10 C. L. White, V. E. Staines, M. H. Staines, (2007), A review of the nutritional value of lupins for dairy cows. CSIRO, <http://www.publish.csiro.au/paper/AR06109.htm>

i MORE INFORMATION

Pulse Australia 'Pulses – Understanding Global Markets': <http://www.pulseaus.com.au/growing-pulses/publications/marketing-pulses#world-pulse-production-calendar>

Pulse Australia 'Pulse Traders': <http://www.pulseaus.com.au/marketing/pulse-traders>

Australian Export Grains Innovation Centre 'Australian Grain Note – Pulses': http://www.pulseaus.com.au/storage/app/media/using_pulses/AGN_Pulse-Note-LR.pdf

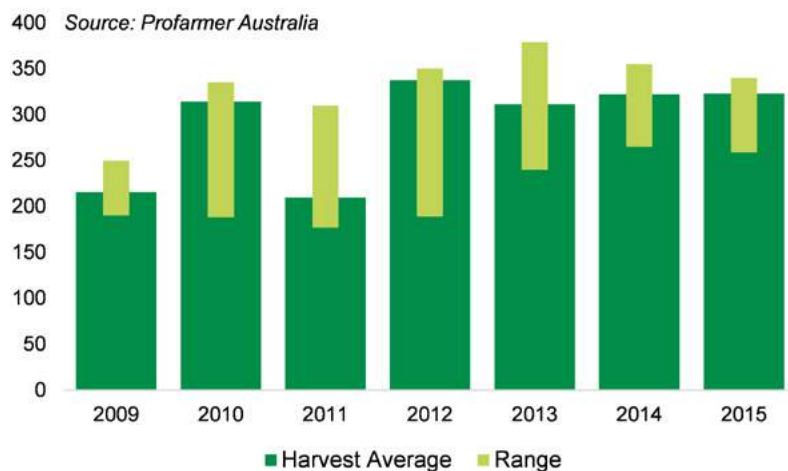
Grain Marketing

13.1 Overview

The final step in generating farm income is converting tonnes of grain produced into dollars at the farm gate. This chapter provides best-in-class marketing guidelines for managing price variability to protect income and cash-flow.

As shown in Figure 1, Kwinana lupin grain values have varied by \$60 to \$160 per tonne during the past seven years. This represents a variability of 25–65 percent. For a property producing 500 t of lupin, this means a \$30,000–\$80,000 difference in income – depending on the timing of sales.

Figure 1: Intra-season variance of Kwinana lupin values in dollars per tonne.



(SOURCE: Profarmer Australia)

13.2 Selling Principles

The aim of a selling program is to achieve a profitable average price (the target price) across the entire business. This requires managing several unknowns to establish the target price and then working toward 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 the grower's 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.

13.2.1 Be prepared

Being prepared and having a selling plan is essential for managing uncertainty. The steps involved are to form 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 key selling principles when considering sales during the growing season and production cycle of the crop are outlined in Figure 2.

Figure 2: *Grower commodity selling principles timeline.*

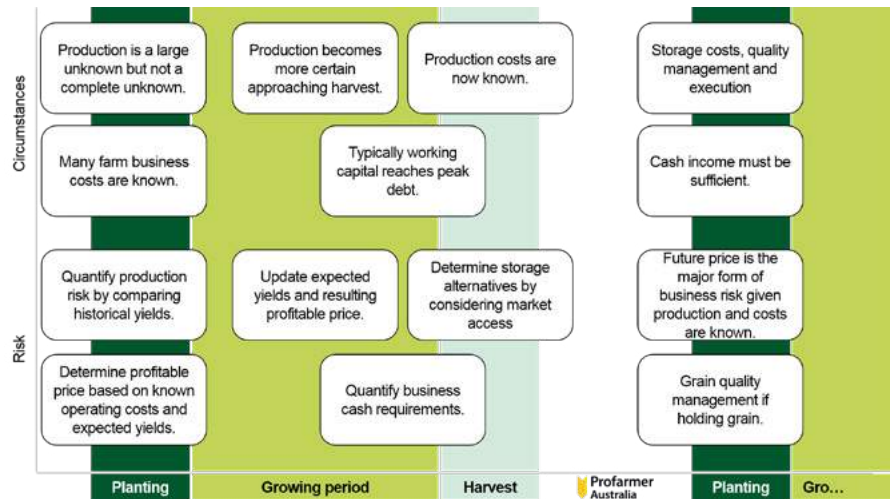


(SOURCE: Profarmer Australia)

13.2.2 Establish a business risk profile – when to sell

Establishing a 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 in Figure 3.

Figure 3: Typical farm business circumstances and risk.



(SOURCE: Profarmer Australia)

A grower’s decision making process for determining when to sell grain will be typically dependent on:

- » Does production risk allow sales?
- » What portion of production risk allows sales?
- » Is the price profitable?
- » Are business cash requirements being met?

13.2.3 Production risk profile of the farm

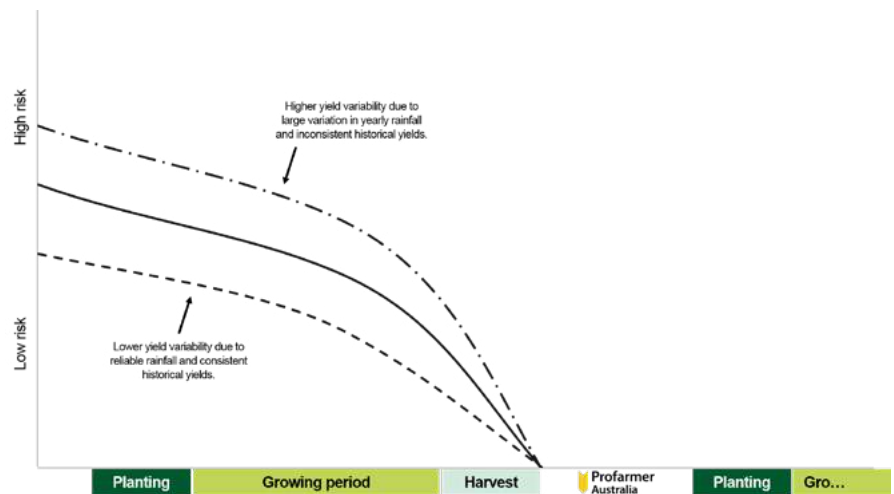
Production risk is the level of certainty around producing a crop and is influenced by location (including climate and soil type), crop type, crop management and time of year.

The general principle is you can’t sell what you don’t have and it is important to not increase business risk by over-committing production.

Establish a production risk profile, such as that outlined in Figure 4, by:

- » Collating historical average yields for each crop type
- » Collating a below average and above average historical yield range
- » Assessing the likelihood of achieving the average based on recent seasonal conditions and seasonal outlooks
- » Revising production outlooks as the season progresses.

Figure 4: Typical production risk profile of a farm operation.



(SOURCE: Profarmer Australia)

As shown in Figure 4, the quantity of crop grown is a large unknown early in the year. However, it is not a complete unknown. You can't sell what you don't have, but it is important to compare historical yields to get a true indication of production risk. This risk reduces as the season progresses and yield becomes more certain. Businesses will face varying production risk levels at any given point in time with consideration to factors including rainfall, yield potential soil type and commodity prices.

13.2.4 Farm costs in their entirety, variable and fixed costs (establishing a target price)

A profitable commodity target price is the cost of production per tonne plus a desired profit margin. It is essential to know the cost of production per tonne for the farm business.

The principle is don't lock in a loss. If a grower is 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 in the Grains Research and Development Corporation (GRDC) 'Farming the Business' manual. This resource also provides a cost of production template and tips about grain selling versus grain marketing. It is available at this link <http://www.grdc.com.au/FarmingTheBusiness>

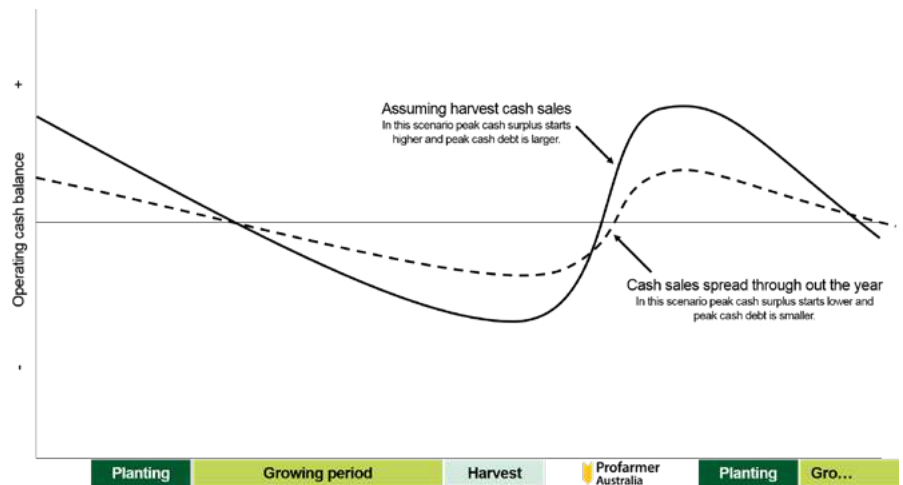
13.2.5 Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables grain sales to be timed so cash is available when required. This prevents having to sell grain below the target price to satisfy a need for cash.

The principle is 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 in Figure 5. Costs are incurred up-front and during the growing season, with peak working capital debt incurred at or before harvest. This will vary depending on circumstance and enterprise mix.

Figure 5: Typical farm operating cash balance.



(SOURCE: Profarmer Australia)

The operating cash flow of a typical farm that assumes a heavy reliance on cash sales at harvest, versus a farm business that spreads sales out throughout the year is also illustrated in Figure 5.

When there is heavy reliance on harvest sales, costs are incurred during the season to grow the crop. This results in peak operating debt levels at or near harvest. This means 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 to generate cash-flow.

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 to fulfil cash requirements.

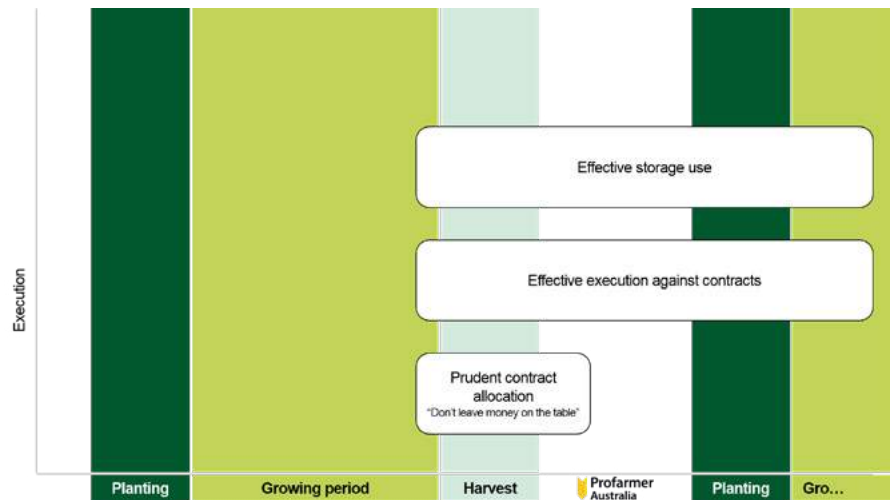
The 'when to sell' steps outlined above result in an estimated production tonnage and the risk associated with that tonnage, a target price range for each commodity and the time of year when cash is most needed.

13.3 Ensuring access to markets

When the selling strategy of the time and method of sale is determined, planning focuses on 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. Planning where to store the commodity is important in ensuring access to the market that is likely to yield the highest return.

Effective storage decisions are outlined in Figure 6.

Figure 6: Effective storage decisions.



(SOURCE: Profarmer Australia)

When a grower has made the decision to sell, the question becomes how to achieve this. The decision about how to sell is typically dependent on:

- » The time of year (determines the pricing method)
- » Market access (determines where to sell)
- » Relative value (determines what to sell).

13.3.1 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 to the bulk grain handling system, private off-farm storage and on-farm storage. Delivery and quality management are key considerations when deciding where to store your commodity.

The principle is that harvest is the first priority. Getting the crop in the bin is the most critical factor to business success during harvest and selling should be planned to allow focus on the harvest.

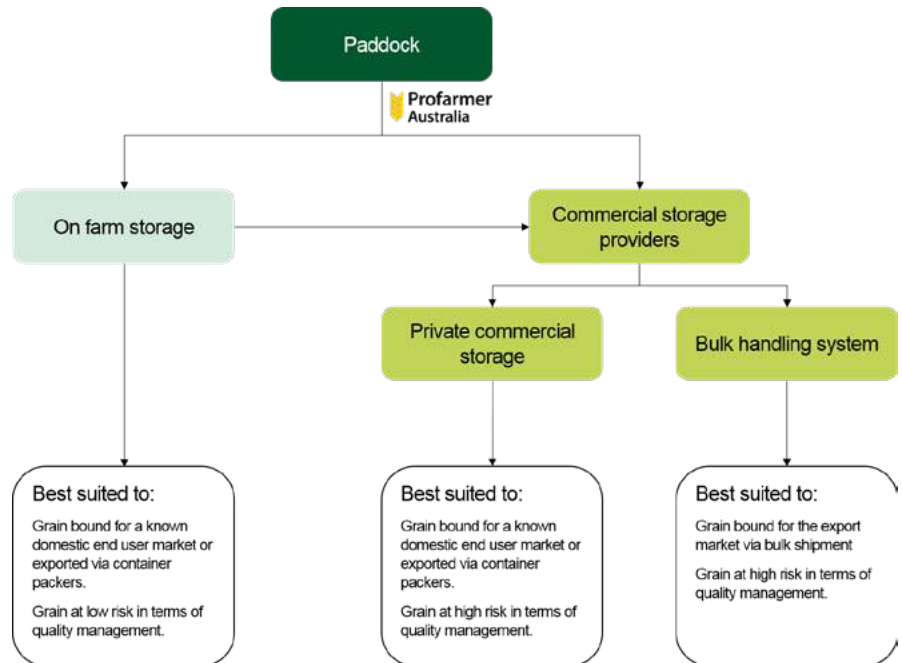
Bulk export commodities that require significant quality management are typically best suited to the bulk handling system. Commodities destined for the domestic end-user market (such as feedlot, processor or container packer) may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on-farm requires prudent quality management to ensure delivery at agreed specifications 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, while also potentially finding a new buyer. 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.

The principle for storage is that it is about market access. Storage decisions depend on quality management and expected markets, as outlined in Figure 7.

Figure 7: Grain storage decision making.



(SOURCE: Profarmer Australia)

13.3.2 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 consist of:

- » Monthly storage fees charged by a commercial provider
- » Capital cost allocation where on-farm storage is used
- » Interest associated with having wealth tied up in grain, rather than cash or against debt.

The price of carried grain needs to be 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

The principle is 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, as illustrated in Figure 8.

i MORE INFORMATION

Grain Trade Australia 'A Guide to Taking out Grain Contracts': <http://www.australiangrainexport.com.au/docs/Grain%20Contracts%20Guide.pdf>

Grain Trade Australia 'Grain Trade Rules, Contracts and Vendor Declarations': <http://www.graintrade.org.au/contracts>

Grain Trade Australia 'Trading Standards': http://www.graintrade.org.au/commodity_standards

Profarmer 'Australian Grain Prices, Analysis and Selling Tactics': <http://www.profarmergrain.com.au>

GrainCorp 'Grain Transact Resource Centre': <http://www.graintransact.com.au>

Australian GrainFlow Network: <http://www.grainflow.com.au>

Emerald Grain: <http://emeraldgrain.com/grower-logins/>

Clear Grain Exchange: <https://www.cleargrain.com.au/get-started>

Daily Grain: <https://www.dailygrain.com.au/>

Figure 8: Cash values versus cash adjusted for the cost of carry (in dollars per tonne).



(SOURCE: Profarmer Australia)

If selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example, in the case of a March sale for March–June delivery on the buyers call at \$300/t plus \$3/t carry per month, if delivered in June, this contract would generate revenue of \$309/t delivered.

Optimising farm gate returns involves planning the appropriate storage strategy for each commodity to improve market access and cover carry costs in pricing decisions.

13.4 Executing tonnes into cash

This section provides guidelines for converting the selling and storage strategy into cash by effective execution of sales.

13.4.1 Set up the tool box

Selling opportunities can be captured when they arise by assembling the necessary tools in advance. The toolbox includes:

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.

Professional services

Professional grain selling 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.

Financial members of Grain Trade Australia (GTA), including buyers, independent information providers, brokers, agents and banks providing over the counter grain derivative products (swaps) can be found at this link <http://www.graintrade.org.au/membership>

13.4.2 How to sell for cash

As with 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, so devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.

Quantity and Quality

When entering a cash contract, there is a commitment to deliver the nominated amount of grain at the quality specified. 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, this relies on prudent execution management to ensure delivery within the contracted period.

Payment terms

In Australia, the traditional method of contracting requires the title of grain to be transferred ahead of payment. This means counter-party risk must be managed.

Typical cash contracting to GTA standards is shown in Figure 9

SECTION 13 LUPIN

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FEEDBACK

Figure 9: Typical cash contracting as per Grain Trade Australia standards.

Grain Trade Australia is the industry body ensuring the efficient facilitation of commercial activities across the grain supply chain. This includes contract trade and dispute resolution rules. All wheat contracts in Australia should refer to GTA trade and dispute resolution rules

Quantity (tonnage) and quality (bin grade) determine the actuals of your commitment. Production and execution risk must be managed.

Price is negotiable at time of contracting
Price basis or price point is important as it determines where in the supply chain the transaction will occur and so what costs will come out of the price before the growers net return.

Timing of delivery (title transfer) is agreed upon at time of contracting. Hence growers negotiate execution and storage risk they may have to manage.

Whilst the majority of transactions are on the premise that title of grain is transferred ahead of payment this is negotiable. Managing counterparty risk is critical.

GTA Contract No.3 CONTRACT CONFIRMATION

GTA Trade Rules and Dispute Resolution Rules apply to this contract

This Contract is confirmation between:



BUYER

Contract No: _____
 Name: _____
 Company: _____
 Address: _____

Buyer ABN: _____
 NGR No: _____

SELLER

Contract No: _____
 Name: _____
 Company: _____
 Address: _____

Seller ABN: _____
 NGR No: _____

The Buyer and Seller agree to transact this Contract subject to the following Terms and Conditions:

Commodity: _____ 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: _____
 Delivery Point and Conveyance: _____ (Delivered, Shipped, Free In Store, Free On Board, Ex-Farm, etc.)
 _____ (Road, Rail, Delivered Container Terminal, Freight, Rated Basing Point, Loading Weight requirements if applicable)

Payment Terms: The buyer agrees to pay the seller within _____. In the absence of a declaration, payment will be 30 days end of week of delivery.

Levies and Statutory Charges: Any industry, statutory or government levies which are not included in the price shall be deducted as required by law.

Disclosures: Is any of the crop referred to in this contract subject to a mortgage, Encumbrance or lien and/or Plant Breeders Rights and/or EPR liabilities and/or registered or unregistered Security interest? NO YES (Please appropriate box) if "yes" please provide details:

Other Special Terms and Conditions:

All Contract Terms and Conditions as set out above and on the reverse of this page form part of this Contract. Terms and Conditions written on the face of this Contract Confirmation shall overrule all printed Terms and Conditions on the reverse with which they conflict to the extent of the inconsistency. This Contract comprises the entire agreement between Buyer and Seller with respect to the subject matter of this Contract.

Recipient Created Tax Invoice (RCTI).

To assist with the processing of the Goods and Services Tax compliance, the buyer may prepare, for the seller, a Recipient Created Tax Invoice (RCTI). If the seller requires this service they are required to sign this authorisation.

Please issue a RCTI (Please)

Incorporation of GTA Trade & Dispute Resolution Rules:

This contract expressly incorporates the GTA Trade Rules in force at the time of this contract and Dispute Resolution Rules in force at the commencement of the arbitration, under which any dispute, controversy or claim arising out of, relating to or in connection with this contract, including any question regarding its existence, validity or termination, shall be resolved by arbitration.

Buyer's Name: _____
PRINT NAME

Buyer's Signature: _____

Date: _____

Seller's Name: _____
PRINT NAME

Seller's Signature: _____

Date: _____

This Contract has been executed and this form serves as confirmation and should be signed and a copy returned to the buyer/seller immediately.

2014 Edition

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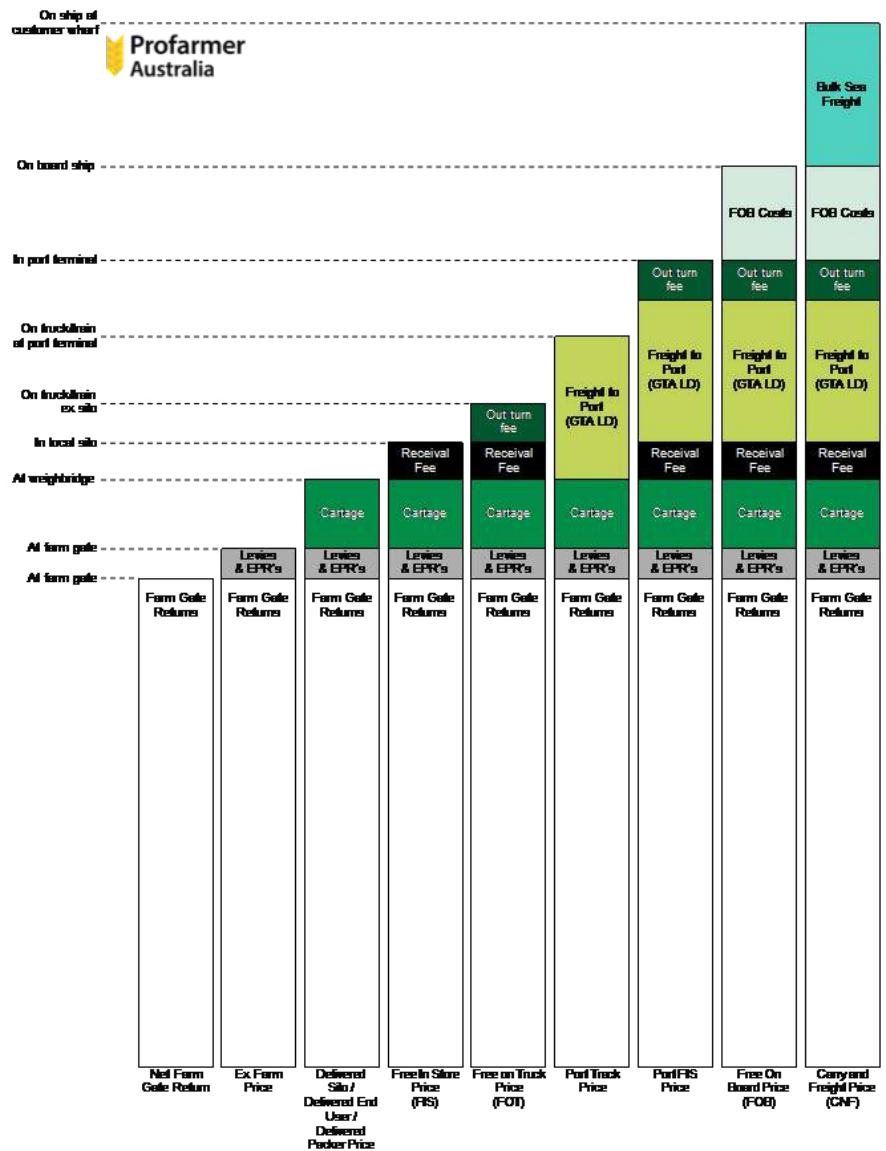
(SOURCE: Grain Trade Australia)

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As outlined in Figure 10, the price point in a cash contract will depend on where the transfer of grain title will occur along the supply chain. It shows the terminology used to describe pricing points along the grain supply chain and the associated costs to come out of each price before growers receive their net farm gate return.

Figure 10: Costs and pricing points throughout the supply chain.



(SOURCE: Profarmer Australia)

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. Availability depends on location and commodity.

Placing a firm offer

Growers can place a firm offer price on a parcel of grain by approaching buyers with a set tonnage and quality at a pre-determined price. The buyers do not have to accept the offer and may simply say no or disregard the offer.

There are increasingly more channels via which to place a firm offer.

One way this can be achieved anonymously is 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. Availability 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 counter-party.

Some bulk handler platforms are also providing facilities for sellers to place firm offers to the market. This includes GrainCorp through its CropConnect product.

A grower can also place a firm offer directly with an individual buyer.

13.4.3 Counter-party risk

Most sales involve transferring the title of grain prior to being paid. The risk of a counter-party defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

The principle is seller beware. There is not much point selling for an extra \$5/t if you don't get paid.

Counter-party risk management includes:

- » Dealing only with known and trusted counter-parties
- » Conducting a credit check (banks will do this) before dealing with a buyer they are unsure of
- » Only selling a small amount of grain to unknown counter-parties
- » Considering credit insurance, or a letter of credit, from the buyer
- » Never delivering a second load of grain if payment has not been received for the first.

It is important to not part with a title of grain before payment, or to 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 through which 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 counter-party risk management. Achieving \$5/t more and not getting paid is a disastrous outcome.

13.4.4 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 with the highest relative value. This achieves price protection for overall farm business revenue and enables more flexibility to a grower's selling program while achieving the business goals of reducing overall risk.

The principle is 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.

MORE INFORMATION

Grain Traders Australia 'Managing Counter-party Risk 14/7/2014': <http://www.graintrade.org.au/sites/default/files/Grain%20Contracts%20-%20Counterparty%20Risk.pdf>

Clear Grain Exchange 'Title Transfer Model': <https://www.cleargrain.com.au/get-started>

GrainGrowers 'Guide to Managing Contract Risk': www.graingrowers.com.au/policy/resources

13.4.5 Contract allocation

Contract allocation means choosing which contracts to allocate grain against at delivery time. Different contracts will have different characteristics (price, premiums-discounts, oil bonuses etc.) and optimising your allocation reflects immediately on your bottom-line.

Consideration needs to be made based on the quality or grades you have available to deliver, the contracts you already have in place and how revenues will be calculated on each contract. Key considerations include whether the contract calculates revenues based on a sliding scale, or on pre-determined quality 'buckets'. Whenever you have more grain to allocate than pre-committed to contracts, it is important to consider the premiums and discounts available in the current cash market as part of your contract allocation decision.

The principle is 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.

13.4.6 Reading 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.

Appetite in pulse markets can be fickle, erratic and the buy-side can be illiquid. Hence monitoring market signals is critical to achieving the best possible returns.

The principle is 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 offering prices \$5/t above the next best bid, it may mean cash prices are susceptible to falling \$5/t if that buyer satisfies its buying appetite. In pulse markets, the spread between the highest and the second highest bidder can be more than \$100/t at times.

Monitoring actual trades against public indicative bids

When trades are occurring above indicative public bids, this might indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids.

Sales execution

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

13.5 Market dynamics and execution

13.5.1 Price determinants for western lupin

Australia is a relatively small player in terms of world pulse production, producing 1.5-2.5 million tonnes (mt) of pulses in any given year versus global production of about 60 mt. Lupin makes up only a small part of this global pulse production, with estimates indicating there is only marginally more than 1 mt being produced annually. Australia, however, makes up a considerable proportion of global lupin production. Australian annual production has ranged from 550-650,000 t in recent seasons, accounting for 50-80 percent of global production and positioning the country as the key global market participant.

There are two major types of lupin grown in Australia. Narrow leafed lupin (Australian sweet lupin) is the predominant type grown, with the bulk of production occurring in WA. Production of narrow leaf lupin is largest in the Geraldton region where it is suited to the area's deep, acid sandy soils. These varieties are also grown throughout the State, including the Kwinana, Albany and Esperance port zones. They are predominately used for stockfeed and, with a relatively small domestic stockfeed market in WA, a large proportion of WA production is exported. Comparatively, the albus lupin is primarily used for human consumption purposes and production – although considerably smaller – is spread throughout New South Wales, Victoria, South Australia and WA.

The major export markets for lupin varies depending on the variety. The export market for albus lupin is primarily Egypt, where it is used for human consumption in the snackfood industry. With the Egyptian import requirement estimated at just 50,000 t each year, a change in Australian production for this lupin type can result in a notable under or over-supply. Comparatively, the major export markets for the narrow leafed lupin consist of South Korea, the European Union (EU) and Japan, which between them import on average 200-350,000 t of Australian lupin each year to be used as stockfeed.

As lupin is predominately exported for stockfeed, the lupin grain is valued in relation to other competing protein commodities. Australia is typically the sole exporter of lupin into the global market. Rather than competing against other export origins, it competes against substitute protein products – the biggest being the soybean complex. Lupin sold into export markets is 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.

The biggest global influence on Australian lupin export values and pricing is the world price and availability of soybean meal. It is the most heavily produced protein that can act as a substitute for lupin.

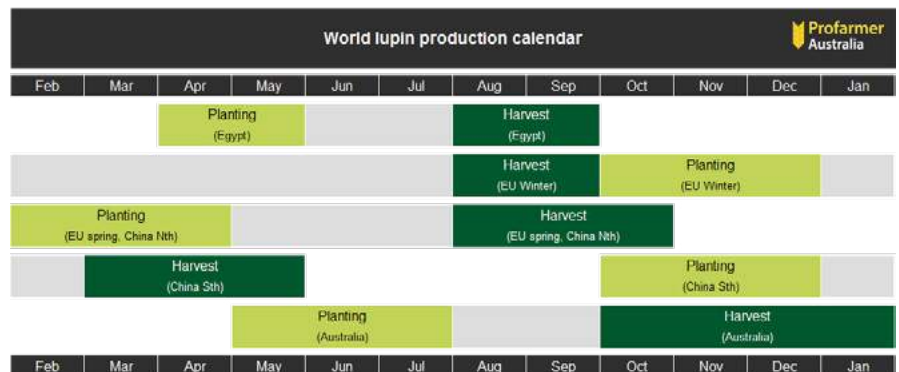
Another major influence on pricing is the lupin production in origins outside Australia. While Australia is by far and away the biggest producer of lupin globally, if production increases in outside regions, this can impact the import requirements for Australian produce in the coming season. This is particularly true in the EU, where increases in production can result in a reduced appetite from neighbouring nations and key importers including Spain and the Netherlands. The global production calendar for lupin is shown in Figure 11.

SECTION 13 LUPIN

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Figure 11: Global lupin production calendar.



(SOURCE: Profarmer Australia)

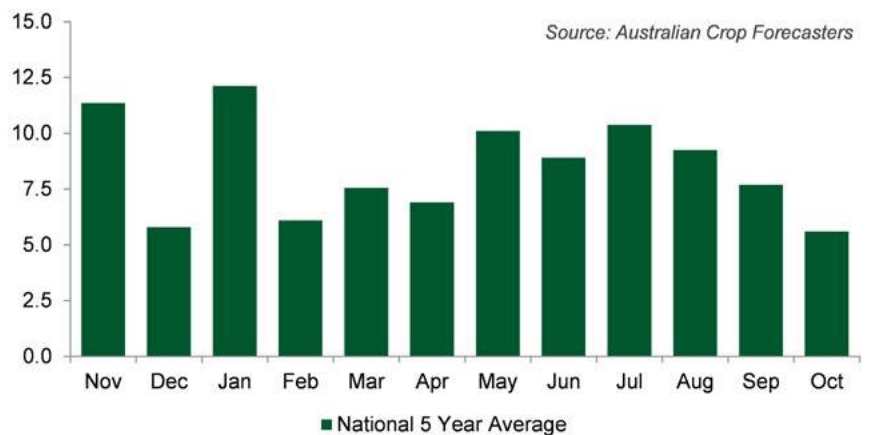
Local influences on Australian lupin pricing include:

- » Domestic production of each lupin variety
- » Availability and quality of local protein feeds
- » Seasonal conditions and the subsequent demand for feed grain.

Appetite for feed grains, including protein feed, can vary considerably in the western growing regions depending on seasonal conditions. Drought has seen sharp increases in appetite for the sweet lupin varieties as graziers are required to increase the volumes of feed they purchase.

Average monthly lupin export pace is outlined in Figure 12 and it highlights that Australian lupin exports are usually strongest shortly after the domestic harvest as buyers seek to move crop to fulfil immediate appetite.

Figure 12: The five-year average monthly lupin export pace from Australia (in thousand tonnes).



(SOURCE: Australian Crop Forecasters)

13.5.2 Ensuring market access for western lupin

The market for the western lupin crop varies greatly depending on the variety grown and the region of production. Narrow leafed lupin, which makes up 95 percent of WA lupin production, is typically sold into the local domestic feed market or exported as stockfeed. WA production exceeds local feed requirements, so a large portion is exported each season (about 60-70 percent). Interest in the human consumption market for lupin is increasing but remains small.

Close to half of the WA lupin crop is exported in bulk, which means the grain bulk handling system is often the most cost effective pathway to get produce to offshore customers. This is particularly prudent for lupin grown in the Geraldton port zone, where a large proportion of the crop is exported. The grain bulk handler should gain scale efficiencies through shipping big volumes.

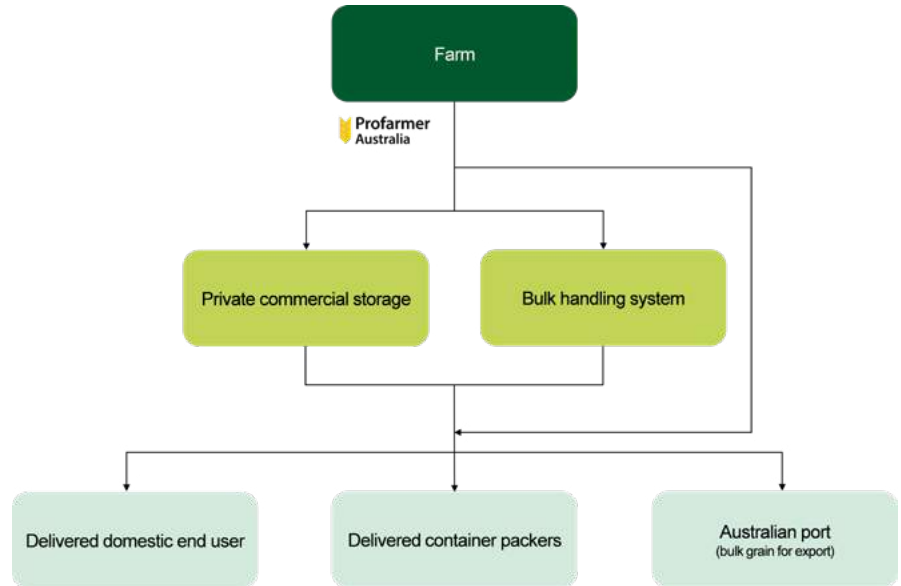
A large proportion of the WA lupin crop is also typically stored and sold out of the grain bulk handling system. But private commercial and on-farm storage is a reasonable alternative for accessing container export and domestic end-user markets. This is particularly prudent for growers outside the core Geraldton and Kwinana port zone production regions. Due to smaller production volumes of lupin grown in Esperance and Albany, most grain tends to be entirely absorbed by the domestic feed market. Private commercial and on-farm storage is likely going to be a more viable alternative to access end-markets.

The domestic feed market absorbs about 30-40 percent of WA lupin production, depending on seasonal conditions. Private commercial and on-farm storage allows greater flexibility in accessing this market when it is most favourable to the grower. This option is popular, given lupin stores well.

Albus lupin is predominately bound for export for human consumption purposes. Egypt remains the main buyer. Production is not big enough to warrant exporting in bulk vessels, which means any export activity for albus lupin 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 lupin that does not make the required specifications for export can be sold into the domestic feed market, with the same market access principles applied for Sweet lupin to be followed. The supply chain flow of lupin in Australia is outlined in Figure 13.

Figure 13: Australian Supply chain flow.



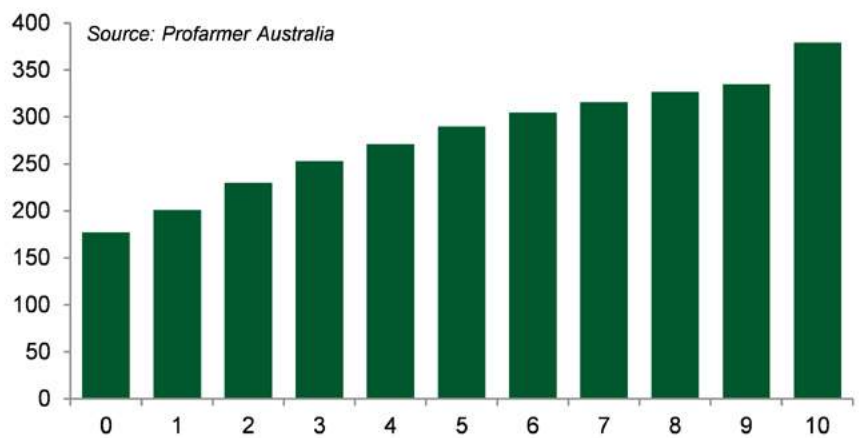
(SOURCE: Profarmer Australia)

Storage decisions should be determined by assessing market access. The large majority of WA lupin is exported in bulk or in containers. Private commercial storage, storage in the bulk grain handling system and on-farm storage can provide efficiencies to market.

13.5.3 Executing tonnes into cash for western lupin

Due to the volatile nature of lupin pricing, setting a target price using the principles outlined in this chapter minimises the risk of taking a non-profitable price or holding out for an unrealistically high price that may not occur. Pricing deciles for lupin, as shown in Figure 14, are provided as a guide.

Figure 14: Kwinana lupin deciles.



(SOURCE: Profarmer Australia)

Selling options for lupin include:

Store on-farm and then sell

This is a common tactic, particularly for Australian narrow leafed lupin varieties. Lupin is safe to store and require less maintenance than cereal grains. It does remain important to monitor quality, particularly for albus varieties, which will be required to meet export specification requirements. There must be consideration of cost of storage in target pricing.

Cash sale at harvest

This is the least preferred option, as buyer demand does not always coincide with harvest. This is particularly the case for albus lupin, where there are limited buyers and an influx of grower selling can push values lower.

Warehouse and then sell

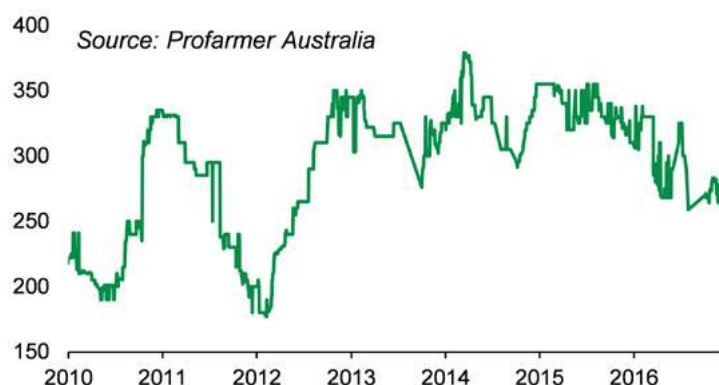
This provides flexibility for sales if on-farm storage is not available. There must be consideration of warehousing costs in the determination of cost of production and target prices. Warehousing lupin is typically available to growers in key production areas of the western region, depending on the particular bulk grain handling site segregation.

There are some forward price mechanisms available for lupin, with traditional fixed volume forward contracts and (less commonly) area contracts. Area-based contracts tend to price at a discount to fixed volume contracts and this discount needs to be weighed up against the level of production risk inherent in each contract.

As with all sales, counter-party risk and understanding contract of sale is essential. Counter-party risk considerations are 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 product.

Long-term Kwinana lupin price history is outlined in Figure 15.

Figure 15: Long term Kwinana lupin price history (dollars per tonne).



(SOURCE: Profarmer Australia).

Current Research

Project Summaries

<https://grdc.com.au/research/projects>

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 the GRDC's research partners with the aim of raising awareness of the research activities each project investment. The GRDC's project summaries portfolio is dynamic: presenting information on current projects, projects that have concluded and new projects which have commenced. It is updated on a regular basis. The search function allows project summaries to be searched by keywords, project title, project number, theme or by GRDC region (i.e. northern, southern or western region). Where a project has been completed and a final report has been submitted and approved a link to, a summary of the project's final report appears at the top of the page. The link to Project Summaries is <https://grdc.com.au/research/projects>

Final Report Summaries

<https://grdc.com.au/research/reports>

In the interests of raising awareness of the GRDC's investments among growers, advisers and other stakeholders, the GRDC has made 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 <https://grdc.com.au/research/reports>

Online Farm Trials

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 'Online trials' <http://www.farmtrials.com.au>

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Milne AgriGroup P/L – Milne Feeds

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Weston Milling

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W <http://dpiwve.tas.gov.au/biosecurity/plant-biosecurity/plant-health-laboratories/tasag-elisa-testing>

SGS Australia

28 Reid Rd
Perth WA 6105
P 08 9373 3500
W www.sgs.com.au

AgriFood Technology

38 Clark Ct
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P 08 9418 5333
W www.agrifood.com.au

AsureQuality

3-5 Lillee Crescent
Tullamarine VIC 3043
P 03 8318 9024
W www.foodprocessing-technology.com

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