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GRDC GROWNOTES™

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

LUPIN

SECTION 4
NUTRITION AND FERTILISER

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]

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

1 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_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 ($CaCl_2$) 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

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
	Lupin	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 layer[10]

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

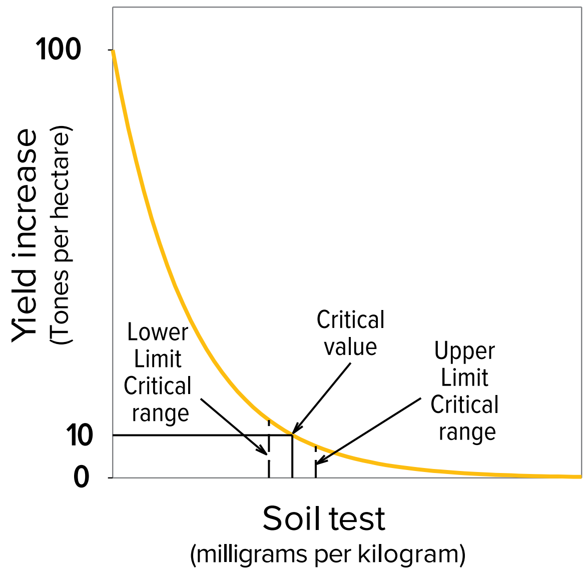
11 Anderson, G, Brennan, R, Bell, R, Chen, W (2015) Making better fertiliser decisions for cropping systems in Western Australia. Soil test – crop response relationships and critical soil test values and ranges, DAFWA Bulletin 4865, Murdoch University

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 leafed lupin.*

	LOCATION											
SYMPTOM	OLD LEAVES				MIDDLE TO NEW LEAVES						TERMINAL SHOOTS	
	N	P	K	Mg	K	Mg	S	Zn	Mn	Fe	B	Ca
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	–	–	–	–	–	–	–	–	–	–	★	★

(SOURCE: DAFWA)

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

	LOCATION										
SYMPTOM	OLD LEAVES		MIDDLE TO NEW LEAVES							TERMINAL SHOOTS	
	N	P	K	Mg	S	Zn	Mn	Fe	Cu	B	Ca
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	–	–	–	–	–	–	–	★	–	★	★

(SOURCE: DAFWA)

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]

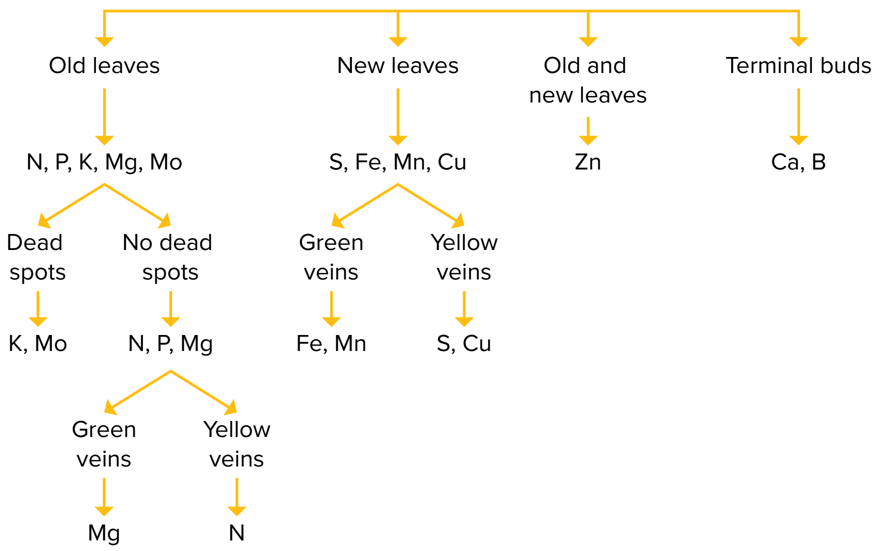
More information about diagnosing nutrient deficiencies is also available on the DPIRD-GRDC MyCrop hub at: https://www.agric.wa.gov.au/mycrop

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

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 'shrivelled' 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]

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

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

[A]Soil test value (mg P/kg) at 90 percent of predicted maximum grain yield, [B]95 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-leafed lupins, https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-narrow-leafed-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

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

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

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)

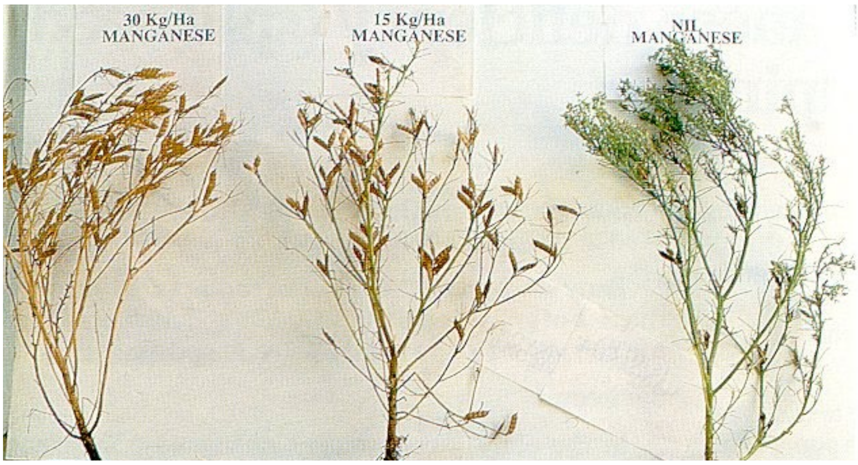


Figure 7: *Symptoms of manganese deficiency in lupin plants include plants with straggly growth and delayed maturity.*

(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 gravely 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/cgi/viewcontent.cgi?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]

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33 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

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 leafed 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 wodjil 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

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^2[C]
Grey sands	32	25	22-28	0.53

[A]Soil test value (mg K/kg) at 90 percent of predicted maximum grain yield, [B]95 percent chance that this range covers the critical soil test value [C] r^2 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

MORE INFORMATION

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

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)

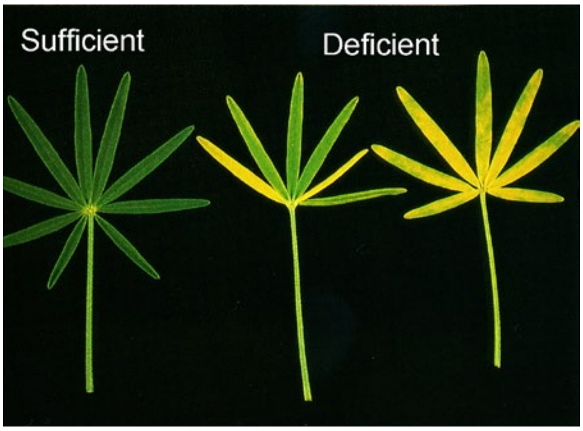

Figure 13: *When there is sulfur deficiency in lupin, as shown on right, older leaflets drop and have total or mottled chlorosis.*

(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 bunchy 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

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/cgi/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 (archea and bacteria) responsible for soil nitrification.

This research differs from previous studies that suggested N fertilisers played a large role in affecting thse microbes.

Testing of WA soils showed a relationship between soil age and the levels of archea and bacteria microbes. Lack of Cu was found to limit the archea 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

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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 (NH_4^+) or nitrate (NO_3^-), 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 N_2 (often abbreviated as percent Ndfa).

Total N fixed by lupin is typically calculated by adjusting the shoot measures of N_2 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

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:

Total N fixed = (shoot N fixed) x 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 N_2 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	Apparent mineralisation of legume N	Soil mineral N autumn 2013	Apparent net mineralisation of legume N
	(kg N/ha)	(% 2011 residue)	(kg N/ha)	(% 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 N_2 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.

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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

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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.wheatbeltnrm.org.au/sites/default/files/knowledge_hub/documents/Soil-acidity-farmers-guide-Bulletin-4784-for-screen.pdf