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GRDC GROWNOTES™

GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

LUPIN

SECTION 4

NUTRITION AND FERTILISER

OVERVIEW | SOIL TESTS | DIAGNOSING NUTRIENT DEFICIENCIES | PLANT TISSUE TESTING | FERTILISER APPLICATION METHODS | NITROGEN (N) | PHOSPHORUS (P) | POTASSIUM (K) | SULFUR (S) | MANGANESE (MN) | MOLYBDENUM (MO) | ZINC (ZN) | IRON (FE) | COBALT (CO) | MAGNESIUM (MG) | BORON (B) | CALCIUM (CA) | NUTRITION BENEFITS OF LUPIN IN THE CROP ROTATION | NITROGEN BUDGETS | ROLE OF LUPIN IN NUTRIENT CYCLING | LUPIN, NUTRIENTS AND SOIL CONSTRAINTS

MORE INFORMATION

GRDC 'Fact Sheet – Better Fertiliser Decisions for Crop Nutrition': https://grdc.com.au/GRDC-FS-BFDCN

GRDC 'Fact Sheet – Soil Testing for Crop Nutrition – Southern Region': https://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-South

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

DPIRD 'MyCrop Lupin Diagnostic Tool': https://www.agric.wa.gov.au/lupin-diagnostic-tool

GRDC Grains Legume Handbook: www.grdc.com.au/Resources/Publications/2008/03/2008-Grains-Legume-Handbook

Nutrition and fertiliser

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 for phosphorus (P) and potassium (K)
- 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 K within four weeks of sowing
- On potentially manganese (Mn)-deficient soils (mainly light sands) use Mn super, deep banded or a foliar Mn spray when first pods are 2.5 cm
- Monitor trace elements/micronutrients (especially if not applied within past 15 years).[1]

There is little new information available about lupin nutrition in southern Australia, but issues are similar to those for other pulses. Lupin crops are often grown on poorer soils or sands, which may require more attention to nutrition planning.

Lupin crops are typically responsive to phosphorus (P) and sulfur (S) and can require nitrogen (N) at sowing if following a 'N-hungry' crop, such as a cereal or canola.

Lupin is a legume able to fix its own N when inoculated with the correct rhizobia bacteria or nodulated from rhizobia in the soil.

On infertile soils in the southern cropping region, N deficiency can develop early in crop development and before enough N has been fixed.

In some cases, using starter N can improve early plant vigour in lupin crops.

Manganese (Mn) and P, at varying rates, are key nutrients that assist lupin crops reach potential yield.

The micronutrients, or trace elements, zinc (Zn) and S can be supplied as needed.

Deep banding of fertiliser, especially P, below the seed at sowing is typically preferred for lupin crops in the southern region. Alternatively, P and other fertilisers can be drilled pre-seeding.

1 GRDC (2013) Fact Sheet 'Better Fertiliser Decisions for Crop Nutrition', www.grdc.com.au/GRDC-FS-BFDCN

FEEDBACK

MORE INFORMATION

CSBP Soil and Analysis Laboratory: www.csbp-fertilisers.com.au/csbp-lab

EP Analysis: www.epanalysis.com.au

Nutrient Advantage Laboratory Services: www.nutrientadvantage.com.au

SGS Australia Ltd: www.sgs.com.au

GRDC 'Fact Sheet – Soil Testing for Crop Nutrition': www.grdc.com.au/GRDC-FS-SoilTestingW

CSIRO Australia 'Soil Fertility Manual': www.publish.csiro.au/pid/1998.htm

4.2 Soil tests

It is advisable to carry out pre-sowing soil tests to determine fertiliser use and application rates for lupin crops in the southern region.

A standard soil test report provides information about:

- Soil type
- Organic carbon
- Soil pH (measured in calcium chloride ($CaCl_2$) or water)
- Available P, K and S
- 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)

Diffuse Gradient Technology Phosphorus (DGT-P) is a relatively new test method being assessed for use with Australian soils. It mimics the action of the plant roots in accessing available P. For more information go to: http://soilquality.org.au/soil_tests/dgt-phosphorous-0-10cm

In southern Australia, Mn deficiency can be difficult to correct with solid fertiliser, particularly on calcareous soils where Mn fertiliser is rapidly immobilised. Foliar Mn applied during podding may therefore be required.

Similarly, Zn deficiency is a concern in many parts of southern Australia and is known to severely affect legume production.

The majority of soils suited to growing lupin crops in the southern cropping region also tend to have very low natural P levels.

When planning soil nutrition strategies, decisions are best made with key objectives in mind, particularly in terms of fertiliser rate selection. This is illustrated in Figure 1, which outlines the four 'Rights' of plant nutrition.[2]

2 GRDC (2013) Fact Sheet 'Better Fertiliser Decisions for Crop Nutrition', www.grdc.com.au/GRDC-FS-BFDCN

Figure 1: *The Four 'Rights' of 4R Plant Nutrition: examples of the scientific principles behind crop nutrition and how they may translate into practical decisions.*[3]

	The 4Rs			
	Source	**Rate**	**Time**	**Place**
Examples of scientific principles	• Ensure balanced supply of nutrients • Product suits soil properties (for example, choice of MAP or DAP)	• Assess nutrient supply (for example, quantity of N or P in a fertiliser product or soil ameliorant) from all sources • Assess plant demand (how much nutrient the crop requires based on target yield)	• Assess dynamics of crop uptake and soil supply (for example, N is frequently applied in-crop based on demand, but current knowledge shows that P must be applied up front) • Determine timing of loss risk (for example de-nitrification, volatilisation, leaching)	• Recognise crop rooting patterns • Manage spatial variability • Plant access to applied nutrient • Nutrient toxicities • Crop choice
Examples of practical choices	• Commercial fertiliser • Livestock manure • Compost • Crop residue	• Test soils for nutrients • Calculate economics • Balance cropremoval	• Pre-plant • At planting • At flowering • At fruiting	• Broadcast • Band/drill/inject • Variable-rate application • Percentage seed bed utilisation

Soil test data from the National Land and Water Resources Audit (NLWRA) shows nutrient status of soils in southern Australia varies considerably, with big areas likely to be responsive to the application of P, K, S, and lime.[4]

Data collated by Incitec Pivot (soil test data, 2010, for SA and Victoria) found 50 percent of soils that year had a pH below 5, 40 percent of soils were low in K and S and soil and tissue tests showed micronutrient deficiencies of 20 percent for Cu and 10 percent for Zn.[5]

3 GRDC (2013) Fact Sheet 'Better Fertiliser Decisions for Crop Nutrition', www.grdc.com.au/GRDC-FS-BFDCN

4 National Land and Water Resources Audit (2008) The National Land and Water Resources Audit Final Report: 2002-2008, http://lwa.gov.au/products/pn22042

5 Christy, B, Riffkin, P, Clough, A, Norton, R, Stott, K, O'Leary, G (2015) Crop Yield Potential Limited by Nutrient Status in the High Rainfall Zone of Southern Australia, http://www.agronomy2015.com.au/papers/agronomy2015final00198.pdf

4.3 Diagnosing nutrient deficiencies

Figure 2: *Common symptoms of nutrient deficiencies in narrow leafed 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: DPIRD)

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: DPIRD)

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 1 and 2.[6]

More information about diagnosing nutrient deficiencies is also available on the Department of Primary Industries and Regional Development (DPIRD)-GRDC MyCrop hub at: https://www.agric.wa.gov.au/mycrop

Tips for identifying nutrient deficiencies in lupin crops in the southern 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.

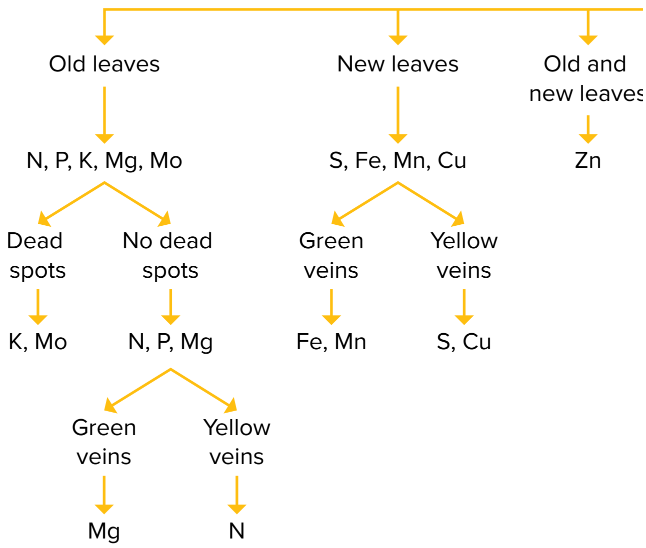

Figure 4: *Flow chart for the identification of deficiency symptoms.*

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

Visual symptoms may be caused by damage from herbicides, insects and/or pathogens

Damage may also be from physiological disorders arising from adverse environmental effects, such as salinity, drought, cold, heat or high temperature stresses and symptoms can be indistinguishable from nutrient deficiency - although it should be obvious if environmental conditions are limiting (such as moisture stress)

6 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

Factors that influence both nodulation and nitrogen fixation can result in symptoms of N deficiency

There can be differences between varieties in the manifestation of symptoms

Visual symptoms in one pulse do not necessarily mean that it is the same in other pulses.

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.

4.4 Plant tissue testing

Plant tissue tests can be used to confirm if crops are deficient in nutrients, particularly trace elements.

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

These tests can provide accurate diagnosis of nutrient deficiencies, particularly where it is difficult to rely on visual symptoms in the paddock.

In some cases, plants might 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 facilitates longer-term monitoring of crop growth and performance.

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

Table 1 shows the elements (based on WA data) that can be provided for lupin crops in a standard plant tissue test report.

Table 1: Recommended minimum plant nutrient levels for a range of pulse crops, during vegetative stages (seedling to budding).[7]

Plant nutrient	Faba bean	Lupin	Field pea
Phosphorus (P) (%)	0.35 – 0.45	0.2 – 0.3	0.25 – 0.4
Nitrogen (N) (%)	4.0	4	-
Potassium (K) (%)	2.0 – 2.5	1.2 – 1.5	1.5 – 2.0
Sulphur (S) (%)	-	0.2 – 0.25	-
Magnesium (Mg) (%)	0.2	-	0.2
Calcium (Ca) (%)	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 (Zn) ppm	>20 – 25	>12 – 14	20 – 30
Boron (B) mg/kg ppm	10	15	10

Young leaves are recommended for micro-nutrient testing.

MORE INFORMATION

GRDC '2016 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

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

4.5 Fertiliser application methods

In SA and Victoria, the key soil nutrient considerations are N, P, K, Mn, molybdenum (Mo), S, Zn, iron (Fe) and cobalt (Co).

There are several methods of applying these nutrients to lupin crops, including:

- Injection
- Surface broadcast
- Broadcast incorporated
- Fertigation
- Banded application
- Foliar application
- Sidedress
- Topdress
- Seed placement.

Some of the benefits and drawbacks of each method of fertiliser application are outlined in Table 2.

Table 2: Benefits and drawbacks of fertiliser application methods.[8]

Method	Advantages	Disadvantages
Liquid Injection	Reduce losses through precise application of liquid nutrients	Slow, expensive (requires specialised equipment
Surface broadcast – unincorporated or mixed only by seeding	Fast, economical	High nutrient losses, low uniformity, P efficiency is only one third to one quarter of banding
Surface broadcast incorporated by prickle chain or harrows	Reduces losses compared to broadcast, improves plant uptake	Slow, non-uniform application, erosion risk, multiple applications
Band application	High nutrient use efficiency, jump-starts early growth, many fields are deficient in P due to soil binding and cold temperatures -banding P makes it easier for plants to grow, it also slows NH_4^+ conversion to NO_3^- (nitrification), reducing the risk of leaching.	Costly, slow, small risk of salt burn toxicity to seeds
Foliar application	Rapid uptake if leaf area is large	Phytotoxicity, high expense, limited to small and/or repeated application
Sidedressing	High nutrient use efficiency	Timing often falls during the wet and busy season, slow process
Topdressing – post-sowing	High nutrient use efficiency	Losses can occur Uneven application is possible
Seed placement	Lower equipment costs, starter effect greater than just meeting nutrient requirements	Can be phytotoxic if too much fertiliser is applied, retro-fitting planters can be expensive, urea and DAP cannot be used

As well as application method, the timing and amount of nutrients applied are important considerations.

8 Cornell University (2016) Northeast Region Certified Crop Adviser Study Resources, Competency Area 4: Nutrient sources, Analyses, Application Methods, https://nrcca.cals.cornell.edu/nutrient/CA4/CA0434.php

4.6 Nitrogen (N)

Figure 5: *Nitrogen deficiency can lead to nodule dysfunction in white and narrow leafed lupin crops and adding small amounts of N can be beneficial.*

(SOURCE: Alan Robson)

Nitrogen influences almost all components of lupin crop growth. It is required for leaf and root growth, nodule formation and chlorophyll production.

The rate of leaf expansion is sensitive to early N levels and even temporary fluctuations in levels of available N can slow the rate of leaf emergence and reduce leaf size. A subsequent increase in the supply of N will not compensate for this loss.

Lupin is a legume and capable of fixing its own N via a symbiotic relationship with bacteria in nodules on its roots.

In the early stages of growth, fertiliser planted with the seed and nitrate-N mineralised from the soil supply the plant until N-fixation begins.

Early sowing and warm soil temperatures promote root growth and progress the start of N fixation.

Too much fertiliser or soil-based N tends to reduce or delay nodulation and slow down N fixation by the root nodules.

Short periods of waterlogging can also reduce nodulation and cause N deficiency.

Using ammonium-based fertiliser can reduce nodule formation and growth. Ammonium has a greater effect than nitrate.

Delaying or separating ammonium application typically increases nodule numbers by improving infection by *Bradyrhizobium lupini* bacteria, responsible for fixing atmospheric N.

Nitrogen fertilisers in small amounts (such as five to 15 kilograms of N per hectare) are typically not harmful to nodulation and can be beneficial by pushing out the early root growth to establish a stronger plant.[9]

Fertilisers containing lower levels of N, such as Mono-Ammonium Phosphate (MAP) or Granulock Z, can be used.

The use of starter N, such as Di Ammonium Phosphate (DAP), banded with the seed when sowing pulse crops, has the potential to reduce establishment and nodulation if higher rates are used.

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

4.7 Phosphorus (P)

Figure 6: *Low phosphorus is shown on severely deficient plants, centre and right, that bend or become twisted before dying.*

(SOURCE: A. Robson)

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

Leaves of P deficient narrow leafed lupin plants frequently drop, after first beginning to die back from the tips.

Leaves of albus lupin that are deficient in P typically show yellow mottling before dying from the tips.

Figure 7: *Symptoms of phosphorus deficiency in the paddock can include smaller plants with thinner stems and fewer lateral branches, as pictured left.*

(SOURCE: DPIRD)

Phosphorus is mobile within plants and can be re-mobilised from leaves, roots and stems to the grain.

In the southern region, it is recommended to drill or band P at seeding.

Banding of P below the seed can increase yields on some soils, particularly those with high P retention.

Experience indicates that placing fertiliser with the seed at sowing at levels higher than 15 to 20 kgP/ha can cause toxicity and reduce crop emergence. Damage tends to be greater in drier soils or where the seed furrrow is narrow (such as when using a disc slot).

Separating seed and fertiliser by banding P below the seed can reduce damage without reducing availability to the plant.

Soil P levels influence the rate of nodule growth, with higher P levels typically producing increased nodule growth.

Phosphorus required per tonne of expected lupin yield, by soil type and Colwell soil test for the top 10 cm soil (mg/kg) is illustrated in Table 3.

Table 3: Phosphorus required per tonne of expected lupin yield, by soil type and Colwell soil test for the top 10 cm soil (mg/kg)[10]

Colwell (mg/kg)	10-15	15-20	20-25	25-30	>30
Rating	Low	Marginal	Adequate	Good	V. good
	Units of P required per tonne of lupin yield expected by soil type and soil P level				
Calcareous Soil	7.5	4.5	3	3	3
Non calcareous soil	6	3	3	3	3

4.8 Potassium (K)

Figure 8: *Potassium deficiency on albus lupin plants.*

(SOURCE: Alan Robson)

10 Rural Directions, South Australia 2016.

If soil tests indicate a deficiency for K, it is advised to apply this nutrient within four weeks of sowing. Excessive K fertiliser leaching can occur on very sandy soils if applied earlier than four weeks after sowing in high rainfall areas because roots are insufficiently developed to capture all of the K.

Potassium chloride (Potash) can be toxic when drilled with the seed.

Potassium is used in many plant processes, including photosynthesis, sugar transport and enzyme activation. It is particularly important in regulating leaf stomata.

Plants that have adequate levels of K tend to be better able to tolerate drought and waterlogging than plants deficient in K.

Lupin crops take up less K than wheat and canola but use it more effectively.

Clay and loam soils have adequate amounts of K for plant growth. But sandy soils can be deficient in K.

High rates of hay or grain removal can result in K deficiency, but lupin roots can access nutrients at greater depth than cereals. Topdressed or banded K fertilisers can help to correct the deficiency.

Figure 9: *In the paddock, low potassium can lead to smaller, thinner plants that are more susceptible to disease, as shown on right.*

(SOURCE: DPIRD)

4.9 Sulfur (S)

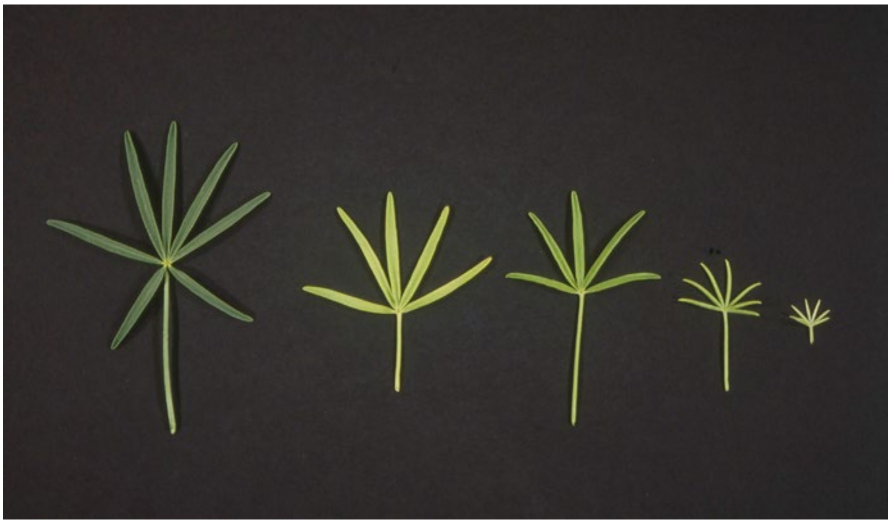

Figure 10: *Narrow leafed lupin plants showing sulfur deficiency symptoms of pale coloured leaves on right.*

(SOURCE: Alan Robson)

Sulfur is needed by lupin plants for seed production and to form chlorophyll and protein. It also helps in nodule formation and is essential for N fixation.

Adequate S is required to maintain N efficiency and low soil S levels tend to result in poor N utilisation by lupin crops.

Leaf symptoms of S deficiency in lupin plants are generally not distinct enough to be detected in the paddock.

When S is deficient, protein synthesis is inhibited and plants become pale, with symptoms similar to those of N deficiency in legumes as shown in Figures 10 and 11.

Figure 11: *As pictured right, low sulfur levels affect growth and colour simultaneously.*

(SOURCE: A. Robson)

A plant tissue test is the best way to confirm any suspicions of S deficiency.

Sulfur deficiency is frequently found in siliceous sand rises in low rainfall areas of SA and Victoria, where depth of sand is greater than 30 cm.

Sulfates, such as nitrates, leach readily in sands and it is recommended S levels are monitored, or a regular application of fertiliser containing S applied.

Single superphosphate contains about 10.5 percent S and there are a range of high-analysis fertiliser products available that contain high levels of S.

When these fertilisers are used, they can help maintain adequate S levels in soils for cropping.

Canola has a large requirement for S and ammonium sulfate and gypsum (calcium sulfate) are often used as extra sources of S in this phase of the rotation.

These products contain about 24 and 17 percent of S respectively.[11]

Sulfur applied as gypsum is less likely to leach, as it is less water soluble than other forms of sulfate.

Deficiencies of S will also tend to occur in crops grown on deeper sandy soils in higher rainfall areas when high analysis fertilisers containing negligible S, such as triple superphosphate (about 1.5 percent S) or DAP (about 1 percent S), have been used for several years.

Figure 12: *Without addressing sulfur deficiencies in the paddock, new leaves and new growth can become very pale green and clumpy, as pictured.*

(SOURCE: DPIRD)

11 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

4.10 Manganese (Mn)

Figure 13: *Manganese deficiency in narrow leafed lupin plants.*

(SOURCE: Alan Robson)

Manganese is needed for many metabolic processes in the lupin plant, including chlorophyll production.

It is relatively immobile and deficiency symptoms occur mostly during pod fill.

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.[12]

On potentially deficient soils (mainly light sands), Mn can be applied as Mn super, deep banded under the seed, or as a foliar spray when first pods are 2.5 cm in length. A repeat application may be required to cover the third or fourth order lateral flowers and pods where there is an extended growing season.

Manganese deficiencies can result in split seed disorder in lupin crops later in the season which results in poor seed viability and germination. Shrivelled seed can result from a severe deficiency of Mn.

12 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

Figure 14: *Low Manganese can lead to split seed disorder, where seeds split through the seed coat and may be shrivelled.*

(SOURCE: DPIRD)

Manganese deficiency can be prevented by applying Mn to the soil (direct drill with seed) or using a foliar spray when pods on the main stem are 2-3 cm long and the secondary stems have almost finished flowering. Mn sulfate is commonly used.[13]

Fertiliser applied to the soil has a good residual value, lasting for several years, whereas foliar sprays will supply Mn only to the crop to which it is applied.

Commercial superphosphates that contain Mn sulfate are available and have a range of Mn concentrations in the fertiliser.

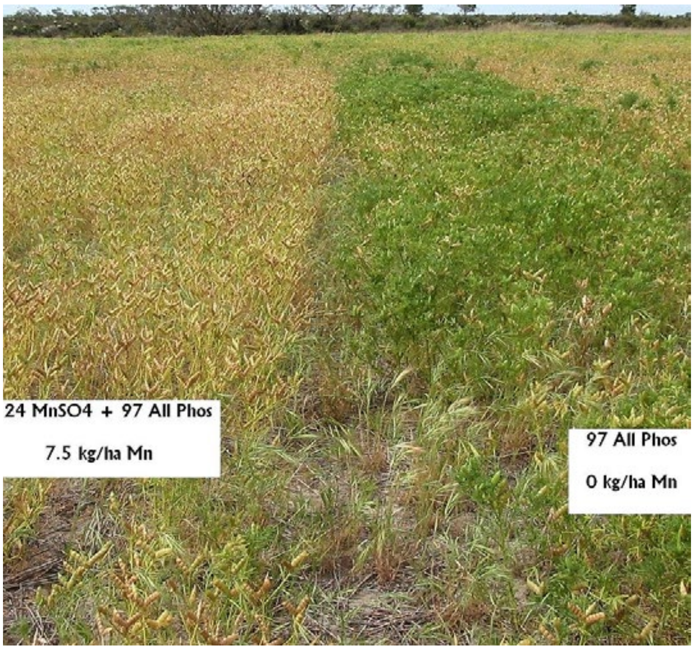

Figure 15: *Lupin plants with low manganese levels, on right without fertiliser treatment, tend to stay green with straggly growth as leaves drop and pods fill on unaffected plants, shown left, with fertiliser.*

(SOURCE: CSBP)

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

Applying 4 kg/ha of Mn sulfate in 75-100 Litres of water directly on to the foliage of lupin crops can be an effective method of controlling split seed disorder.[14]

But foliar sprays sometimes fail and the development stage of the seed at the time of spraying is critical.

Manganese deficiency is of particular consideration for growing lupin crops on the calcareous soils of the Eyre and Yorke peninsulas, the upper to mid-south-east regions of SA and potentially on alkaline soils in the SA, VIC and southern NSW Mallee areas.

In some cases, Mn deficiency has been induced in paddocks that have been treated with clay to increase fertility and reduce water repellence.

4.11 Molybdenum (Mo)

Figure 16: *Molybdenum deficiency (pictured right) 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 and is part of the enzyme that converts nitrate-N (the form taken up from the soil) to nitrite-N (the form used by plants). It is also essential for N fixation.

Lupin crops are often grown in acid soils in parts of the southern region and these are commonly low in Mo.

Management of Mo deficiency in 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.[15]

Proteoid roots can increase the availability of Mo in albus lupin.

Coating seed with Mo fertiliser is one way to supply Mo to deficient seeds.

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

But 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), potentially causing a breakdown of the seed dressing used to control Brown leaf spot disease of lupin (*Pleiochaeta setosa*).[16]

4.12 Zinc (Zn)

Figure 17: *Zinc deficiency in lupin crops can cause irregular dark blotches on tips of older leaves.*

(SOURCE: Alan Robson)

Zinc is involved in the enzyme systems of plants and is needed for protein synthesis, hormone production, carbohydrate metabolism and membrane stability.

It is taken up from the soil solution as water-soluble Zn and lupin plants have been shown to be less efficient than other winter crops at accessing this nutrient from the soil.

Across SA and VIC, lupin crops are grown mainly on sandy soils that are typically low in most nutrients, including Zn.

Zinc deficiency is common on the calcareous sands of the Eyre and Yorke peninsular areas.

Albus lupin is more sensitive than narrow leafed lupin to Zn deficiency.

Leaf symptoms of Zn deficiency are typically not distinct enough to be detected in the paddock.

Plants with mild Zn deficiency produce new leaves that are slightly paler than non-deficient plants.

Severe Zn deficiency causes irregular, dark brown blotches on the tips and margins of older leaves and the crown. It can also delay flowering.

Other symptoms are a reduction in stem length and increased branching of lateral roots.

16 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

FEEDBACK

4.13 Iron (Fe)

Figure 18: *Iron deficiency (shown on right) in lupin plants can affect nitrogen fixation.*

(SOURCE: Alan Robson)

Iron is required by the lupin plant for effective N fixation, so the nodule initiation phase is the most sensitive to low soil Fe levels.

Plants with Fe deficiency produce bright yellow young leaves.

Iron deficiency is rare on acid soils. On alkaline and calcareous soils, narrow leafed lupin tends to be more sensitive than albus lupin to Fe deficiency.

Waterlogged alkaline soils can also induce a temporary deficiency that typically dissipates when the soil dries out.

Iron deficiency will typically occur in lupin crops grown on soils with a pH above 7.0 if the soil aeration is reduced slightly and temperatures are cold.

Lupin crops grown on fine-textured, alkaline soils that become saturated with water in winter will typically show bright yellowing of young leaves.

Figure 19: *In the paddock, lupin crops with iron deficiency tend to have smaller, paler plants with chlorotic new leaves.*

(SOURCE: Alan Robson)

Foliar application of Fe will reduce symptoms of deficiency and improve plant growth, but has not been shown to increase grain yields.[17]

The yield potential of lupin on alkaline soils tends to be lower than for most other grain legumes.

Lime-induced chlorosis symptoms are also a strong indicator in SA and Victoria of the presence of free lime in the soil. Crops in free lime often fail or are very unproductive. These symptoms and pH soil tests will show that sowing lupins in these areas should be avoided.

4.14 Cobalt (Co)

Cobalt is needed by rhizobia bacteria to fix N. Therefore, Co deficiency reduces the N concentrations in the lupin plant shoots.

Narrow leafed lupin is more sensitive than albus lupin to Co deficiency.

Seeds with low Co concentrations sown into soils deficient in Co tend to produce poorly nodulated lupin roots with ineffective nodules and the crop may become N deficient.

17 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

FEEDBACK

4.15 Magnesium (Mg)

Figure 20: *Magnesium deficiency (shown centre and right) in narrow leafed lupin plants can be seen as lighter, pale leaves.*

(SOURCE: Alan Robson)

As the central atom of the chlorophyll molecule, the main roles of Mg in the lupin plant are photosynthesis and P transport.

Magnesium accumulates in the seeds of plants that are rich in oil because the oil is accompanied by an accumulation of lecithin, a fat that contains P.

Therefore, the P content of a crop can occasionally be increased by adding a Mg fertiliser instead of a P fertiliser.

Magnesium also assists in P metabolism, plant respiration, protein synthesis and the activation of several enzyme systems in the plant.

When Mg deficiency symptoms first show in lupin, typically there has not yet been damage to the plant.

Plants grown without any Mg are a lighter green, with some mild interveinal yellowing appearing on new and old leaves.

The 'old-leaf' symptom is very specific to Mg deficiency, along with the presence of small bronze spots distributed randomly over the entire leaflet.

These spots expand only slightly and do not merge to form areas of necrosis. These old leaves slowly turn a dull greyish green.

The new-leaf symptom is vastly different, with the thin and spiky leaflets arranging into a cluster and the tips swiftly dying – but with little distortion such as curling or twisting. The whole plant finally turns a dull green colour.

4.16 Boron (B)

Figure 21: *Boron deficiency in narrow leafed lupin crops is rare but can lead to abnormal lateral growth on plants.*

(SOURCE: Alan Robson)

Boron deficiency is unlikely to be a major issue in lupin crops in the southern region. But, if diagnosed, foliar applications of fertilisers can act rapidly to minimise yield loss.

Timing and rate of application is important to avoid irreversible damage.

Soil application of B generally lasts longer than foliar B products, but can be leached from acidic, sandy soils.

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.[18]

In Australian trials, lupin has tended not to show significant shoot or grain yield responses to applied soil or foliar B fertiliser.

4.17 Calcium (Ca)

Calcium is necessary for growth and functioning of lupin root tips.

Calcium pectate is a component of the cell walls, increasing mechanical strength of the plant, and tends to be stored in the leaf. It also activates many plant enzyme systems and neutralises organic acids in the plant.

A large supply of Ca is needed for nodulation and N fixation by lupin and other legumes.

The roots of some legumes have a higher Ca demand during the stages of root infection by rhizoctonia hypocotyl rot (*Rhizoctonia solani*) than during plant growth.

The first sign of Ca deficiency in lupin plants tends to be a shortening of the lateral roots. Soon the tips of these laterals turn a brown colour, which extends some distance back from the tips.

Signs of Ca deficiency on plant tops soon appear. New leaves that are not fully expanded have the ends of leaflets remaining tightly closed, as though they are stuck together.

18 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, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1042&context=bulletins

These needle-like ends (about one-third to one-half of the length of the leaflet) do not turn necrotic for some time, although appear similar to water stress to the whole leaf.

As seen in many other plant species suffering from Ca deficiency, petioles of new leaves bend and finally collapse, although the leaves may show no more than a few chlorotic areas.

Some bending of the main stem can occur, indicating the role of Ca in stem wall construction.

Young growth soon develops necrotic tipping of the unopened leaflets, followed by the collapsing of the petioles. Eventually, the new growing tip decays before any elongation of the petioles can occur and old and middle leaves become mottled and chlorotic, die and shed.

4.18 Nutrition benefits of lupin in the crop rotation

Incorporating lupin or other legumes into crop rotations in the southern region provides nutrition benefits to the whole farming system by increasing supply of organic/mineral N and reducing the need for N fertilisers.

Lupin crops require high levels of N for growth and most of this comes from the atmosphere through symbiotic N fixation with rhizobia.

After the lupin crop is harvested, a 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 biomass, the more organic/mineral N is left behind in the paddock because of an abundance of roots, branches and leaves.[19]

Organic N compounds must be converted to inorganic forms. This is carried out by soil microorganisms as they 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 usually highly valuable to the system.

Research has found legume N can substantially reduce the need for fertiliser N inputs – often by up to 40-80 kgN/ha in SA – and lifts productivity of subsequent cereal and canola crops. On average, lupin crops across southern Australian soils have been shown to fix up to 20 kgN/ha per tonne of dry matter.[20]

4.19 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 lupins 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'.[21]

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 'Fact Sheet – Break Crop Benefits – West': http://grdc.com.au/Resources/Factsheets/2011/03/Break-Crop-Benefits-West

GRDC 'Ground Cover Supplement – Flexible Farming' (June 2012): http://gc-supplement.realviewdigital.com/?iid=66229&startpage=page0000015#folio=8

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/cgi/viewcontent.cgi?article=1009&context=bulletins

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 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

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:

Total N fixed = (shoot N fixed) x root factor.

National 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.[22]

As shown in Table 4, 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.[23]

Table 4: 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.[24]

Crop grown in 2011	Soil mineral Nautumn 2012	Apparent mineralisation of legume N	Soil mineral Nautumn 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**	

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 Ndfa across 35 growers' crops indicated these crops were deriving about 70 per cent 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 was 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.

They advised 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.[25]

22 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

23 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

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 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 indicated 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 are on average 18-34 kg N/ha, representing 10-12 per cent of the residue legume N.[26]

A general rule of thumb 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 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.[27]

4.20 Role of lupin in nutrient cycling

Researchers in WA 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.

The 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 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 when 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.[28]

26 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

27 GRDC (2014) Fact Sheet – Nitrogen fixation of crop legumes: basic principles and practical management, www.grdc.com.au/GRDC-FS-NFixation-Legumes

28 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

DPIRD 'Soil acidity – A guide for WA Farmers and Consultants': https://www.wheatbeltnrm.org.au/sites/default/files/knowledge_hub/documents/Soil-acidity-farmers-guide-Bulletin-4784-for-screen.pdf

4.21 Lupin, nutrients and soil constraints

The dominant taproot of narrow leafed lupin plants can delve as deep as 2.5 m, which is significantly deeper than field pea and barley – but 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 spores, which may allow penetration of hardpans and access to underlying water and nutrients.

Unlike WA, the south eastern cropping region has only small areas where soil acidity (low pH) is a significant impediment to lupin grain production. But these areas are expanding as parts of higher rainfall zones acidify.

For lupin, acidity in topsoils mainly affects nutrient availability and nodulation and is, most pronounced when pH is less than 5.5.[29]

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.[30]

29 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

30 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