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LENTIL

SECTION 7

NUTRITION AND FERTILISER

Nutrition and fertiliser

Key points

- Lentil nutrition is like other pulses.
- Lentil is relatively responsive to phosphorus and some trace elements (Mn, Zn in particular).
- Lentil benefit from nitrogen at seeding if following a 'nitrogen-hungry' crop like cereals or canola.
- Visual symptoms of nutrient deficiency in lentil are similar to the other pulses.
- Soil must be moist to allow roots to take up and transport nutrients.
- Soil pH influences the availability of most nutrients.
- Soil temperature must lie within a certain range for nutrient uptake to occur.

7.1 Essential nutrients for plants

There are 16 nutrients that are essential for the healthy growth of all plants. They are classified as mineral nutrients and non-mineral nutrients.

Non-mineral nutrients are carbon (C), hydrogen (H) and oxygen (O). These nutrients are found in the atmosphere and water and used in the process of photosynthesis. The main product of photosynthesis is carbohydrate (as well as oxygen and water to a lesser extent); it is carbohydrate that drives the growth and development of plants.

Mineral nutrients are absorbed by plants from the within the soil. Mineral nutrients can be classed as either macronutrients or micronutrients; the former being required by plants in far greater quantities than the latter.

Table 1: The classification of mineral nutrients.

Macronutrients	Micronutrients
Nitrogen (N)	Boron (B)
Phosphorus (P)	Chlorine (Cl)
Potassium (K)	Copper (Cu)
Calcium (Ca)	Iron (Fe)
Magnesium (Mg)	Manganese (Mn)
Sulfur (S)	Molybdenum (Mo)
	Zinc (Zn)

Five other elements are also essential to plant growth. These are sodium (Na), cobalt (Co), silicon (Si), nickel (Ni) and vanadium (Va). Deficiencies of these nutrients are extremely rare; problems with these elements are more likely to be due to toxicity than deficiency.[1]

Macronutrients

Macronutrients are those elements that are needed in relatively large amounts. Nitrogen, phosphorus and potassium are classed as primary macronutrients and calcium, magnesium and sulfur are considered secondary macronutrients.

Macronutrients are used in the greatest quantity by plants and usually become deficient first.

High yields of crops for grain or forage will place greater demand on the supply and availability of major nutrients such as phosphorus, potassium and sulfur. Nitrogen, phosphorus, potassium and, at times, sulfur are the main nutrients commonly lacking in Australian soils. Each crop type varies slightly in its requirement for nutrients and may display deficiency symptoms if requirements are not met.

Micronutrients

Micronutrients are those elements that plants need in small amounts such as iron, boron, manganese, zinc, copper, chlorine and molybdenum. In Western Australia, it is rare for chronic deficiencies of micronutrients to occur in lentil.

A healthy plant

Healthy plants have a greater potential to ward off disease, pests, and environmental stresses leading to higher yields and improved grain quality.

Too little, too much, or the incorrect proportion of nutrients, can cause nutritional problems in lentil. If the condition is extreme, plants will show visible symptoms that can sometimes be accurately identified. If correctly diagnosed, visual symptoms provide an immediate evaluation of nutrient status. Visual symptoms do not develop until a major effect on yield, growth or development has occurred. Unfortunately,

1 CSIRO Publishing (2006) Australian Soil Fertility Manual. CSIRO Publishing

production can be affected when nutrient disorders are sub-clinical and before there is any visual evidence of a problem.

7.2 Considerations when diagnosing nutrient disorders

There is limited nutritional information about lentil in Australia. However, lentil nutrition is like that of other pulses in that responses to phosphorus and potassium can be common. Lentil can require nitrogen at seeding, before it fixes enough of its own nitrogen. This is especially so if following a 'nitrogen-hungry' crop like cereals or canola, which can drain the soil of readily available mineral nitrogen.

Symptoms of nutrient deficiency appear to be similar to the other pulses.[2]

The following points should be considered when diagnosing nutrient disorders:

- Considerable yield loss may have occurred before any visual symptoms became apparent.
- Visual symptoms of nutrient disorders in lentil can be very similar to and confused with damage from herbicides, insects, and pathogens.
- Plants can have multiple nutrient disorders which mask and confuse the visual symptoms of individual nutrient problems.
- Damage to plant material may also be from physiological disorders arising from adverse environmental effects such as salinity, drought, cold, heat or high temperature stresses. Such symptoms can be indistinguishable from nutrient deficiency, so obvious environmental conditions like moisture stress should always be considered.
- Factors that influence both nodulation and nitrogen fixation can result in symptoms of nitrogen deficiency.
- There can be differences between cultivars in the manifestation of symptoms.
- Visual symptoms in one pulse do not necessarily mean that it is the same in other pulses.

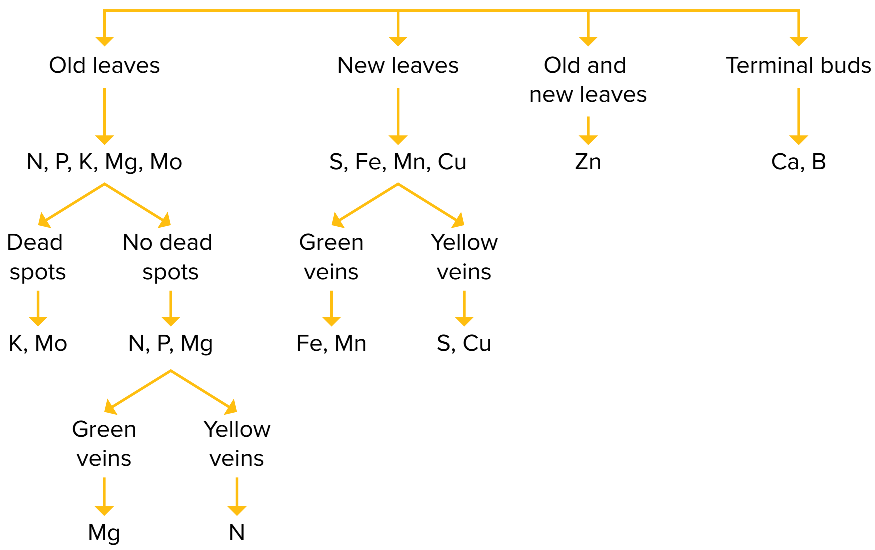

Figure 1: *Flow chart for the identification of deficiency symptoms.*

2 Grain Legume Handbook (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee

Identifying nutrient deficiencies

To differentiate between nutrient deficiency symptoms that appear similar, the following should be undertaken:

- Know what a healthy plant looks like in order to recognise symptoms of distress;
- The affected area of the crop needs to be identified and its appearance noted. For example, plants should be checked for discolouration (yellow, red, brown etc), death (necrotic), wilted or stunting, etc.
- The pattern of symptoms in the paddock needs to be identified (patches, scattered plants, crop perimeters);
- Affected areas need to be assessed in relation to soil type (pH, colour, texture) or elevation; and
- Individual plants need to be examined closely to identify detailed symptoms such as stunting, wilting and where the symptoms are appearing (whole plant, new leaves, old leaves, edge of leaf, veins etc).

If more than one problem is present, typical visual symptoms may not occur. For example, water stress, disease, or insect damage can 'mask' a nutrient deficiency.

If two nutrients are simultaneously deficient, symptoms may differ to when there is one nutrient deficiency alone.

Micronutrients are often used by plants to process other nutrients, or work together with other nutrients, so a deficiency of one may appear like another. For instance, molybdenum is required by pulses to complete the nitrogen fixation process.

Table 2 highlights symptoms of key nutrient deficiencies.

Table 2: Key to nutrient deficiencies in field pea that may be applicable to lentil.

Deficiency	Old to middle leaves					Middle to new leaves					New leaves to terminal shoots						
symptom	N	P	K	Mg	Zn	N	Zn	Ca	Mn	B	S	Mg	Mn	Fe	Cu	Ca	B
Chlorosis (yellowing)																	
Complete											x			x			
Mottled	x	x		x			x	x	x				x				
Interveinal										x			x				
Cresent form								x									
Nercosis (tissue death)																	
Complete			x		x												x
Distinct areas (including spotting)	x		x	x			x				x	x	x				
Margins		x	x		x	x				x							x
Tips		x			x	x		x			x		x	x	x		x
Pigmentation within necrotic (yellow) or chlorotic (dead) areas																	
Opaque														x			
Light brown					x	x					x		x				
Brown		x						x									
Pink			x	x			x	x				x		x			
Malformation of leaflets																	
Rolling in of margin			x	x									x	x			
Wilting					x	x									x		
Twisting								x								x	
Puckering													x		x		
Malformation of leaves																	
Cupping							x										
Rosetting							x										x
Tendril distortion					x							x	x				x
Internode shortening		x					x										x
Stem lesions							x										x
Petiole collapse																x	
Root distortion							x	x		x						x	x

MORE INFORMATION

For detailed information see the GRDC Factsheet: Soil testing for crop nutrition (western region) https://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-West

7.3 Soil and plant tissue testing

Soil tests estimate how much nutrient is likely to be available to plants and plant tissue tests measure how much nutrient plants have absorbed. By comparing test results to critical levels, soil and plant tissue tests gauge the adequacy or otherwise of nutrients for plants and whether plants are likely to respond to additions of nutrients in fertilisers.

Pulse crops can have different requirements for critical nutrient levels, meaning test results for one crop are not necessary correct for another crop type.[3]

In Western Australia, there are no critical soil test levels specific to lentil, however criteria for lupin are a useful guide (Table 3).

3 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

Plant tissue testing can be used to diagnose a deficiency or monitor the general health of the pulse crop.

Tissue tests can diagnose nutrient disorders before visual symptoms become apparent. This is important because by the time noticeable symptoms appear in a crop, the yield potential can be markedly reduced. When visual symptoms do appear, tissue tests can unequivocally determine which nutrient or nutrients are the cause of the problem. Technology is enabling quicker analysis and reporting of results, which enables foliar or soil-applied remedies to be applied in a timely manner for a quick crop response.

Plant tissue tests are very useful when fine-tuning nutrient requirements, particularly when aiming to fully capitalise on available moisture.

Most plant tissue tests diagnose the nutrient status of the plant at the time it is sampled. Results cannot reliably indicate the effect of a particular deficiency on grain yield.

Table 3: Critical nutrient ranges for soils in the western region.

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	9	6–12
		Yellow sands in northern region	22	21–23
		Grey sands in southern region	12	10–15
		Yellow sands in southern region	30	25–37
	Canola	All	19	17–25
K	Wheat	All	41	39–45
		Yellow sands	44	34–57
		Loams	49	45–52
		Duplexes	41	37–44
	Lupin	Grey sands	25	22–28
	Canola	All	44	42–45
S	Wheat	All	4.5	3.5–5.9
	Lupin	All	N/A	N/A
	Canola	All	6.8	6.0–7.7

Source: DPIRD via Grains Research and Development Corporation (2014) Soil testing for crop nutrition (western region). Grains Research and Development Corporation, https://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-West

MORE INFORMATION

Refer to: Lentil: The Ute Guide for detailed descriptions and images of nutrient deficiencies. Available from the GRDC book shop on the GRDC website https://grdc.com.au/resources-and-publications/all-publications/publications/2008/11/lentils-the-ute-guide

7.4 Nutrition requirements of lentil

Table 4: Critical nutrient levels for lentil at flowering.

Nutrient	Plant part	Critical range*
Phosphorus (%)	YML**	0.3
Potassium (%)	YML	1.8
Sulphur (%)	YML	0.2
Boron (mg/kg)	YML	20
Copper (mg/ka)	YML	3
Zinc (mg/kg)	YML	20

* Any nutrient level below the critical range will be deficient; any level above will be adequate. ** YML = youngest mature.

Source: Grain Legume Handbook for the Pulse Industry (2008) https://grdc.com.au/Resources/Publications/2008/03/2008-Grains-Legume-Handbook

Fertiliser recommendations for lentil, as with most pulses, tend to very generic. Some say this is often based more on convenience and availability, rather than meeting the specific nutrient requirements of the crop.[4] Fertiliser recommendations need to be more prescriptive, and should consider:

- soil type;
- rotation;
- yield potential of the crop;
- plant configuration (row spacing, type of opener and risk of 'seed burn');
- soil analysis results; and
- effectiveness of inoculation techniques.

Fertiliser toxicity

All pulses can be affected by fertiliser toxicity, usually caused by excessive salts from fertiliser being too close to imbibing seeds and germinating seedlings.

Potential for toxicity increases in highly acidic soils, sandy soils, and soils where moisture conditions are marginal at seeding. Placement of fertiliser relative to seed has a major effect on susceptibility. High rates of salty fertilisers (e.g. those containing muriate of potash and/or sulfate of ammonia), wide row spacings (so higher concentration within rows), narrow sweeps and drilling seed and fertiliser together all contribute to increased risk.

MORE INFORMATION

See Section 3 Pre-planting for more information on Inoculation.

7.5 Nitrogen (N)

Nitrogen is essential for plant growth as it is a part of every living cell. Plants require large amounts of nitrogen for normal growth and development.

Lentil should not normally need nitrogen fertiliser if the plant has achieved effective nodulation.[5]

Lentil seed should be inoculated with the correct strain of rhizobia, particularly when:

- lentil has not been grown in a paddock for 5 or more years; or
- the soil pH ($CaCl_2$) is less than 5.7.

Lentil can also take up nitrate from the soil should nitrate carry over from preceding crops or be mineralised from organic pools over summer/autumn. This, therefore, reduces the potential for nitrogen losses by leaching. Leaching occurs when nitrogen is washed down with water into the soil profile below the plant root zone where it cannot be accessed by plants. Leaching of nitrates contributes to soil acidification. In

4 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

5 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

FEEDBACK

MORE INFORMATION

See Section 6 Plant and growth physiology

some countries where leaching is important, growing lentil can have a positive impact on groundwater quality due to reduced leaching.

Deficiency symptoms

The first visual sign of nitrogen deficiency in lentil is overall 'paleness' of the plant. This will occur even before a general reduction in plant growth. There may be a 'cupping' of the middle to new leaves. With time a mottled chlorosis of old leaves slowly develops with little sign of necrosis (plant death).

If, based on visual plant symptoms, nitrogen deficiency is suspected, the next step is to check the nodules of the plant. Nodules should be plentiful and healthy.

Photo 1: *Nitrogen deficiency (left) relative to a well-nodulated plant (right).*

(Photo: ICARDA)

Photo 2: *Nitrogen deficiency: the plant shows signs of stunting, yellowing and poor growth.*

(Photo: C. Toker)

Photo 3: *Nitrogen deficiency: the plant shows signs of stunting, yellowing and poor growth.*

(Photo: W. Hawthorne)

Some situations where nitrogen fertiliser may be required include:

- when recommended inoculation procedures have not occurred; and
- late seeding or low fertility soils, where rapid early growth is critical in achieving adequate height and sufficient biomass to support a reasonable grain yield.

Application

The use of starter nitrogen in a compound phosphorus-nitrogen fertiliser (e.g. MAP or DAP), banded with the seed (i.e. sown with seed, but without touching the seed) when sowing pulse crops has the potential to reduce establishment and nodulation if high rates are used. Hence, caution needs to be taken with rates of application.

7.6 Phosphorus (P)

Phosphorus is essential for many growth processes in plants. Soil phosphorus levels influence the rate of nodule growth. The higher the phosphorus level the greater the nodule growth. Adequate phosphorus is essential for seed germination, root development, and in the ripening process of grain (and seed).

Deficiency symptoms

Phosphorus deficiency is difficult to detect in the absence of a comparison to phosphorus-adequate plants because initial symptoms are smaller or stunted leaves and plants. Leaf colour only starts to alter when plants are very phosphorus deficient.

Symptoms of phosphorus deficiency may take time to develop due to the initial reserves of phosphorus in the seeds still supporting the plant.

Visual symptoms appear first on the oldest leaves as a mildly mottled chlorosis over much of the leaf. These symptoms might be confused with either nitrogen or sulfur deficiency. However, the middle and new leaves remain a healthy green meaning the plant overall does not appear pale.

As symptoms on old leaves develop, round purple spots may appear within areas of dark green in an otherwise mildly chlorotic leaf.

MORE INFORMATION

FEEDBACK

Further information on AM can be found at https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-96-Supplement-Soil-Biology-Initiative/Phosphorus-uptake-and-mycorrhizal-colonisation-what-is-the-link

It is important to note that lentil is deemed medium in its responsiveness to phosphorus fertiliser. However, zinc status must be adequate to achieve a response to phosphorus.[6]

Arbuscular mycorrhiza (AM) is a fungi involved in a symbiotic relationship with plant roots. AM assists plants in taking up nutrients that are immobile in the soil such as phosphorus, zinc and copper from both the soil and fertiliser. In Australia, there is little recognition of the need for AM in lentil.[7]

Lentil requirements

Phosphorus recommendations for lentil don't exist for Western Australia. Phosphorus requirements can be established with a soil test and appropriate rates of required fertiliser determined.

Application

Phosphorus fertiliser is most effective when drilled or banded with seed. Acceptable methods include:

- band (direct placement an inch or so below the seed); and
- drill with seed (without allowing direct contact with the seed if fertiliser contains nutrients other than phosphorus).

Although less effective, phosphorus can also be broadcast (topdressed) and ploughed or disced in. Phosphorus rates should be increased if broadcasting it.[8]

Germinating lentil is extremely sensitive to salts in fertilisers, especially those containing nitrogen, potassium and sulfur. Changes in seeding techniques to narrow seeding points or disc seeders with minimal soil disturbance, and wider row spacing has increased the concentration of fertiliser near the seed. This, in turn, increases the risk of toxicity.

If heavy phosphorus applications are required to correct nutrient deficiencies, fertiliser (containing salts) should be applied before or during seedbed preparation to prevent potential damage to the lentil seedling.[9]

Starter fertilisers containing both phosphorus and nitrogen have been recorded as most effective when soils are cold because roots are stimulated by a readily available supply of both nutrients.

6 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

7 A Smith, S Smith, M Manjarrez (2012) Phosphorus uptake and mycorrhizal colonisation: what is the link? Grains Research and Development Corporation, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-96-Supplement-Soil-Biology-Initiative/Phosphorus-uptake-and-mycorrhizal-colonisation-what-is-the-link

8 R Mahler (2005) Northern Idaho Fertilizer Guide: Lentils. University of Idaho, CIS1083, http://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1083.pdf

9 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

7.7 Potassium (K)

Potassium is one of the three primary macronutrients. It is required by plants in greater quantities than phosphorus.[10]

Deficiency symptoms

When suffering from potassium deficiency, older leaflets of the plant show symptoms first. Initially some parts of the paddock are more affected, for instance in between windrows and lighter soil types. Margins and tips of leaflets lose their green colour and become yellow-green. Reddish pigmentation is also seen on some leaflets. These leaflets often drop from the plant.

Symptoms progress up the plant when deficiency persists. Necrotic patches may develop on leaflets. Stems of some plants may also develop reddish-brown anthocyanin pigmentation (blue, violet or red pigment found in plants). Older leaves may show slight curling and then a distinct browning of leaf margins before eventually dying.[11]

Lentil requirements

Lentil appears to be similar to other pulses, like field pea and especially lupin, that are less susceptible to potassium deficiency compared with faba bean, which is quite susceptible.

Potassium fertilisers on lentil are warranted where soil test results are low. Fertiliser responses are likely where soil test levels, using the Colwell test, fall below critical levels (refer to Table 5).

Table 5: Potassium fertiliser rates for lentil.

Soil test K (0 to 30cm)[1] (ppm)	Application rate[2]	
	K_2O (kg/ha)	K (kg/ha)
0 to 50	75	63
50 to 75	45	38
more than 75	0	0

1 Sodium acetate-extractable K in the 0 to 30cm depth.
2 K_2O x 0.83 = K, or K x 1.20 = K_2O

Application

Potassium can be incorporated into the seedbed by whatever method is most convenient for the grower. Acceptable methods include:

- broadcast (topdressed) and ploughed or disced in;
- band (direct placement an inch or so below the seed); and
- drill with seed without allowing direct contact with the seed because potassium fertilisers, especially muriate of potash, are very salty and lentil seedlings are extremely sensitive to salts.

If heavy potassium applications are required to correct nutrient deficiencies, it is usually best to broadcast fertiliser before seeding, although application at or after seeding can be just as effective.

10 CSIRO Publishing (2006) Australian Soil Fertility Manual. CSIRO Publishing

11 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

7.8 Calcium, magnesium and sulfur

Calcium, magnesium and sulfur are secondary macronutrients.

They are as important to plant growth as the primary macronutrients but usually they do not need to be applied as fertiliser because plants can source a sufficient supply from the soil. In rare cases where these three elements are deficient, plant growth can be depressed as much as the primary macronutrients.[12]

Calcium (Ca)

Calcium function is mainly in the leaves of the plant and as part of the cell walls. Calcium is important for root development and in developing growing points.

Calcium does not move freely from older to younger tissue, resulting in younger tissue always being lower in calcium content.

Deficiency symptoms

Deficiencies are first shown at the tips of young shoots and are usually denoted by reduced plant height. In pulses, there is a broad yellowing of the leaves between the veins at the centre of the base of leaflets.[13] Plant roots are less numerous, less branched, and the root tips are thickened.

Magnesium (Mg)

Magnesium serves many functions in the plant. Magnesium is involved in photosynthesis. Magnesium and nitrogen are the only nutrients that are constituents of chlorophyll.[14]

Deficiency symptoms

Magnesium deficiency first appears on young leaves as a chlorosis (loss of chlorophyll meaning loss of green colour). This chlorosis can extend down the sides of the leaflets. The symptom on leaflets is yellow to yellow-green with a green area remaining around the central leaf vein.

Prevalence of magnesium deficiency results in light brown necrotic areas developing on the leaf tips or margins of the plant. The basal leaves usually remain green in severely affected plants. There is no evidence of anthocyanin pigmentation (blue, violet or red pigment) on magnesium-deficient plants.

Application

To enhance crop yields in a magnesium-deficient scenario, magnesium oxide (MgO) can be applied.[15]

Sulfur (S)

Sulphur is present in plants as proteins, in some oils, and as sulfates. Without adequate sulfur, the lentil plant is unable to 'fix' enough atmospheric nitrogen to meet its needs.

Elemental forms of sulfur acidify the soil (reduce soil pH) if, and when, they convert to the plant-available sulfate form. Superphosphate and gypsum (calcium sulfate) do not affect soil pH. Lighter, sandier soils, compared to heavier clays, are more prone to sulfur deficiency because supply is lower and there is less buffering capacity.[16]

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12 CSIRO Publishing (2006) Australian Soil Fertility Manual. CSIRO Publishing

13 R Mahler (2005) Northern Idaho Fertilizer Guide: Lentils. University of Idaho, CIS1083, http://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1083.pdf

14 CSIRO Publishing (2006) Australian Soil Fertility Manual. CSIRO Publishing

15 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

16 CSIRO Publishing (2006) Australian Soil Fertility Manual. CSIRO Publishing

Deficiency symptoms

Symptoms on sulfur-deficient plants can resemble those of nitrogen deficiency but usually occur on younger plant material. Chlorosis (yellowing) on sulfur-deficient plants firstly affects the leaves near the top of the plant, while leaves near the base remain green.

With increased severity of sulfur deficiency, chlorosis extends over the entire plant. The pattern of chlorosis development enables the differentiation of sulfur deficiency compared to nitrogen deficiency. Some leaflets become completely yellow, wither and drop from the plant. Reddish-brown pigmentation can appear on the stems and leaves and the plants are slender and small.

Lentil requirements

The need for sulfur is closely related to the amount of nitrogen available to the plant. This is because both nutrients are constituents of proteins and associated with the formation of chlorophyll. Use of soil and plant tissue tests are the best way to gauge sulfur requirements.

Table 6: Sulfur fertiliser requirements of lentil.

Soil test S (0 to 12 inches)		S application rate
(ppm SO_4-S)	(ppm S)	(kg/ha)
0 to 10	0 to 4	17
> 10	> 4	0

Application

Where soil phosphate levels are adequate, an application of a low rate of gypsum is a cost-effective long-term method of correcting sulfur deficiency.[17] Sulfate of ammonia is an option when low rates of nitrogen are also required by the plant.

Elemental sulfur fertiliser should be avoided on lentil as this form of sulfur is too slowly available for the plants actual requirements.[18]

7.9 Boron

Boron is essential in the formation of new plant tissue: the growing points. It is also essential for effective nodulation and nitrogen fixation in pulses, and in satisfying rhizobial requirements.[19] Boron deficiency is rare but toxicity is common on some soil types.

Toxicity symptoms

Boron toxicity appears in alkaline, sodic soils, usually in medium to low rainfall areas. It is particularly prevalent in salt-lake areas in the south-east. Subsoils can have large accumulations of boron.

Shallow (0–10 cm) and deeper (to 30 cm and beyond) soil tests provide a good indication of the suitability of soils (paddocks) for growing lentil. Soil testing will also provide an indication as to the impact boron (in toxic levels) might have on plant growth and rooting depth.

Root pruning and therefore premature senescence or droughting because roots cannot access moisture deeper in the soil profile are common symptoms of boron toxicity. The most characteristic symptom of boron toxicity in lentil plants is chlorosis (yellowing) of the tip and serrated margins of leaflets, and the tip of stipules on lower leaves. Older leaves are usually most affected. Light brown necrotic patches occur

17 R Mahler (2005) Northern Idaho Fertilizer Guide: Lentils. University of Idaho, CIS1083, http://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1083.pdf

18 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

19 CSIRO Publishing (2006) Australian Soil Fertility Manual. CSIRO Publishing

and later develop on yellow areas. The necrotic areas expand to one-third of leaflets and, if severe, some withering, necrosis (death) of leaf tips or margins occurs. Leaflets can separate. Anthocyanin pigmentation (blue, violet or red pigment) does not appear with boron toxicity.

All current varieties of lentil are rated as intolerant or moderately intolerant of high levels of boron that is associated with soil sodicity and alkaline soil.[20] These slight differences in tolerance can be of practical significance for variety performance in the field.

Photo 4: *Boron toxicity in lentil showing typical leaf tip symptoms.*

(Photo: W. Hawthorne, formerly Pulse Australia)

Photo 5: *Boron toxicity in lentil.*

(Photo: M. Raynes, formerly Pulse Australia)

Deficiency symptoms

Boron deficiency has a dramatic effect on the root system of lentil.

The first symptom on a boron deficient plant is yellowing on the tip and margins of leaflets of young entire expanded leaves. This 'bronzing' effect is partially due to red-brown pigmentation on the upper surfaces of leaflet margins. The tips and margins of affected leaflets start to die and the terminal buds turn rusty brown in colour.

The young buds and leaflets die progressively from the tip. Thus, axillary bud development is enhanced. Plant roots are also stunted and thick, with dark tips like those occurring on calcium-deficient plants. Roots become brown, with lateral extremities showing shortening and thickening.

20 Grains Research and Development Corporation (2016) Lentil: The Ute Guide. Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/all-publications/publications/2008/11/lentils-the-ute-guide

Deformed flowers are a common plant symptom of boron deficiency. Many plants may respond by reduced flowering and improper pollination as well as thickened, curled, wilted and chlorotic new growth.

Application

Lentil grown in some circumstances can respond to boron applications. It is always critical to consider that, **as lentil is very vulnerable to boron toxicity, a correct deficiency diagnosis must be made before considering boron applications.**

Soil-applied boron fertiliser should always be broadcast, never banded.[21]

7.10 Copper (Cu)

Both copper and zinc deficiencies have a major effect on flowering and seed production. When very deficient, plant growth will also be affected.

Copper and zinc both have an important role in legume nodulation and nitrogen fixation. Copper has a role in cell wall constituents of plants.

Lentil requirements

Lentil has a greater requirement for copper than chickpea. The critical concentration of copper in the youngest tissue of lentil is estimated as 4.6 mg copper per kilogram (chickpea's requirement is 2.6 mg copper/kg).[22]

Deficiency symptoms

Symptoms of copper deficiency may not appear until flowering, hence there may be little effect on vegetative growth.

Copper deficiency symptoms appear on the younger leaves of the plant, whilst the rest of the plant remains a normal green colour. Wilting and rolling of the leaflet ends of fully opened leaves becomes apparent.

The leaflets on the top leaves of each stem are smaller than usual. Plants produce small leaves with fewer leaflets on the young shoots. In these circumstances, leaves usually wither and appear rust-brown in colour. Shoot elongation is also reduced due to insufficient development of the terminal growing point.

Flowering may be delayed in lentil, as it is in field peas. Flowers can appear quite normal; however, few pods and seeds form.[23]

7.11 Iron (Fe)

Iron is a catalyst in the formation of chlorophyll, and also acts as an oxygen carrier in the plant (CSIRO Publishing 2006). **Iron is strongly immobile in plants.**

Iron deficiency is extremely rare. It is observed occasionally on alkaline, high pH soils. It is usually associated with waterlogging.[24]

Deficiency symptoms

Iron deficiency can be confused with manganese and magnesium deficiency. Lentil appears more prone to iron deficiency compared to faba and broad beans.

Due to iron being immobile within plants, symptoms appear first on younger leaves at the top of the plant. These leaves become chlorotic (even bright yellow) over the entire leaf. The deficiency can spread to older leaves and new growth can cease. Stems become slender and shortened.

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21 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

22 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

23 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

24 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

If the deficiency becomes more severe, leaflets can wither and die; withering occurs from the leaf tip back towards the base.

Yellowing between leaf veins can progress to completely yellow plants (Photo 7). Contrast in colour between old and new leaves is much stronger with iron deficiency compared with that of manganese deficiency.

Iron chlorosis can be transient, with deficiency symptoms largely disappearing at a time coinciding with increases in soil temperature and day length during reproductive growth.

Iron deficiency symptoms tend to be very transient and correspond to periods of waterlogging. An iron-deficient lentil crop can achieve a rapid recovery once the soil begins to dry out.[25]

Application

Sulfate of ammonia can improve absorption of iron and so should be considered for nitrogen and sulfur fertiliser applications if iron is deficient.

Lentil varieties can exhibit a marked difference in sensitivity to iron chlorosis; this can be overcome through plant breeding. Most current lentil varieties are considered tolerant to all but extreme situations.

Photo 6: *Lentil suffering from waterlogging, not to be confused with iron deficiency.*

(Photo: W. Hawthorne, formerly Pulse Australia)

25 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

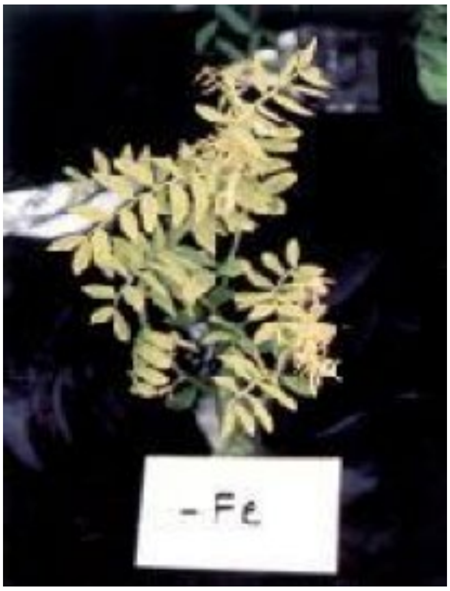

Photo 7: *Iron deficiency in lentil.*

(Photo: ICARDA)

Photo 8: *Iron deficiency in lentil.*

(Photo: W. Hawthorne, formerly Pulse Australia)

7.12 Manganese (Mn)

Manganese promotes germination and accelerates maturity of the plant. Furthermore, the presence of manganese may increase the availability of phosphorus and calcium.[26]

Toxicity symptoms

Manganese toxicity can occur in well-nodulated lentil grown on soils of low pH.

Symptoms appear on new leaves first and then develop in mid and older leaves. This is the opposite to toxicities such as phosphorus.

Small purple spots appear from the margins on young leaves and in slightly older leaves take on a reddish colouration.

Photo 9: *Manganese toxicity.*

(Photo: ICARDA)

Photo 10: *Manganese toxicity.*

(Photo: ICARDA)

26 CSIRO Publishing (2006) Australian Soil Fertility Manual. CSIRO Publishing

Deficiency symptoms

Manganese deficiency is most common on deep leached and coastal sands, gravelly eroded soils, blue mallet, blue mallee and gravelly, fluffy red morrel. It is commonly associated with drier, fluffy soil conditions, usually showing up in patches or parts of paddocks.

Manganese deficiency has been observed occasionally on alkaline, high pH soils.

Manganese-deficient plants are a lighter green colour on younger expanded leaves. Very small spots can develop later on both the surface of leaflets and the stipules of these leaves. Spots are generally found between the leaflet veins on the leaf surface.

Manganese-deficient plants often lose many of their leaflets. In some circumstances, symptoms can extend to the middle leaves. Colour ranges from browning on tops of leaves and new growth, to necrosis over much of the leaf.

Deficiency later in the growing season can lead to seeds being discoloured, split, deformed, or having a brown spot or cavity in the centre.

Application

Manganese fertiliser can be applied at seeding, or as a foliar application later. In lupin it has been shown that manganese banded below seed is more effective than banded with the seed, which in turn is much more effective than manganese topdressed onto the soil surface before seeding.[27]

7.13 Molybdenum (Mo)

Molybdenum is required by rhizobia in root nodules and also for plant growth, particularly under acid soil conditions.

Molybdenum is often deficient in acid soils. Lentil grown on acid soils can respond to molybdenum fertiliser applications as it is present in the soil in only small amounts.

Deficiency symptoms

Due to its role in nitrogen fixation, molybdenum deficiency causes symptoms of nitrogen deficiency.

Leaves of nitrogen-deficient plants are lighter yellow than those of molybdenum-deficient plants. Symptoms start with chlorotic interveinal mottling of older leaves. Leaves, flowers, and pods are reduced, as well as biomass and yield.

In severe deficiency conditions, molybdenum causes leaf wilting and disorders. In addition to growth depression, there are fewer and smaller flowers, and many fail to open or mature. Again, this leads to lower grain yield.

Molybdenum-deficient plants may contain high nitrogen levels. The presence of high nitrogen in a chlorotic, apparently nitrogen deficient plant, is thus evidence for molybdenum deficiency.

Application

Soil testing to assess the molybdenum status of the soil is currently not commercially available. However, molybdenum can easily be applied in granular and liquid fertilisers when planting the crop and as a foliar spray. It should not be applied to seed.[28]

27 P White, B French, A McLarty (2008) Producing lupins. Department of Primary Industries and Regional Development Western Australia, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1009&context=bulletins

28 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

7.14 Zinc (Zn)

Both zinc and copper are important in nodulation and nitrogen fixation in pulses.

Deficiencies in these two micronutrients have a major effect on flowering and seed production. When extremely deficient, plant growth can be affected.

Deficiency symptoms

Zinc deficiency appears as a reduction in internodal growth and results in a rosette growth habit. The younger leaves of zinc-deficient plants initially become pale green in colour. Pigmentation (reddish-brown) takes place on the margins of upper surfaces of leaflets and on the lower portions of the stems.

Plants are small; the areas between veins turn yellow, becoming yellower on the lowest leaves. Maturity can be delayed.

Lentil requirements

Although there is a lack of Australian research on zinc responses in lentil, it is considered to have a relatively medium demand for zinc.

Zinc fertiliser should be applied if there is a history of zinc deficiency or other evidence of a likely response. Recommendations for lentil are conservatively based on a general recommendation for all crops:

- <0.8 mg/kg on alkaline soils; and
- <0.3 mg/kg on acid soils.[29]

Application

Zinc can be applied in numerous ways:

- incorporated into the soil prior to seeding;
- as a seed treatment;
- as a fertiliser at seeding; and
- as a foliar spray.

Incorporated into the soil prior to seeding

As zinc is not mobile in the soil, fertiliser zinc needs to be mixed into and evenly distributed through the soil, usually by cultivation after zinc is applied onto or into the soil. In reduced-tillage seeding systems, such mixing can take many years.

In the first year after application, zinc may not be not fully available to plants so a foliar zinc spray may be required.

Seed treatments

Zinc seed treatments may be a cost-effective option in some situations. Results with zinc seed treatments are variable.

Fertilisers applied at seeding

A range of phosphate-based fertilisers either contain, or can be blended with, a zinc additive which can then be applied at seeding.

Foliar zinc sprays

Foliar application of zinc is relatively common as this method often fits in with herbicide or early fungicide applications.

29 W Lindsay, W Norwell (1978) Development of a DTPA soil test for zinc, iron, manganese and copper. Proceedings from the Soil Science Society of America 42: 421-428, https://dl.sciencesocieties.org/publications/sssaj/abstracts/42/3/SS0420030421

Photo 11: *Zinc-deficient lentil.*

Photo: ICARDA

7.15 Lime

Lime is used to reduce acidity in soil (raise pH). Calcium in lime becomes available to plants as lime neutralises acidity.

If lentil is grown on acidic soils, lime applications may be necessary as lentil yield can be reduced on soils with pH 5.4 ($CaCl_2$) or lower. A key limiting factor is poor nodulation on low pH soils that, consequently, limits lentil production. In some areas, growing lentil on low pH acidic soils may not be considered economical.[30]

7.16 Soil pH and toxicities

Soil pH influences the availability of most nutrients. Occasionally some nutrients are made so available that they become toxic and inhibit plant growth. For example, on some acid soils, aluminium and manganese levels may restrict plant growth, usually by restricting root growth and rhizobia.

Table 7: Pulse reactions to nutrient toxicities.

	Boron	Aluminium	Manganese
Chickpea	sensitive	very sensitive	very sensitive
Faba bean	tolerant	sensitive	sensitive
Lentil*	very sensitive	very sensitive	very sensitive
Lupin*	*	tolerant	tolerant
Field pea	sensitive	sensitive	sensitive

* Lentil and lupin are not usually grown on high boron soils

Source: Southern Lentil: Best Management Practices Training Course (2016), Pulse Australia

30 R Mahler (2005) Northern Idaho Fertilizer Guide: Lentils. University of Idaho, CIS1083, http://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1083.pdf

Aluminium (Al)

Aluminium toxicity can develop in lentil that is well nodulated but grown on soils of low pH.

There are no initial visual symptoms of aluminium toxicity in lentil other than slow, stunted growth and plants appearing miniature and dark green. Roots, especially seminal roots, are extremely stunted with many laterals appearing dead. Symptoms may be confused with phosphorus deficiency. Later in the season, because of poor root growth, plants prematurely senesce.

Salinity

Delays in germination occur with increasing levels of salinity in lentil. After germination, the first signs of salinity damage, due to excess ion accumulation in saline conditions, are necrosis of the outer margins and yellowing of the older leaves.

Salinity intensifies anthocyanin pigmentation (blue, violet or red pigment) in leaves and stems in red lentil; while leaves and stems of green lentil appear yellow. Leaves die and separate due to accumulation of ions. Salinity also reduces flower production and pod setting.

Lentil varieties differ in their tolerance to salinity. Nipper⍉ is the only variety that shows any salt tolerance. All other varieties are intolerant.

7.17 Determining fertiliser requirements

Prior to the planting of lentil, fertiliser requirements must be determined. Specifically, this refers to the types of fertiliser required and the rate(s) they are to be applied.

Fertiliser required is a combination of knowing:

- the current nutritional status of the soil; and
- the nutrient removal by the crop.

Current nutritional status of the soil

Soil types vary in terms of nutritional status.

Different soil types may have different nutrient reserves which vary in availability during the growing season, or are unavailable due to the soil's pH. This is often the case with micronutrients; in this case, foliar sprays can be used to correct any deficiencies.

Important factors that contribute to determining the current nutritional status of the soil include:

- a soil test;
- paddock history;
- soil type; and
- personal or local experience.

Plant tissue tests are also helpful in identifying the nutritional status of the plant (which reflects nutrient availability from the soil) once the crop is growing. These tests can assist in fine-tuning nutrient requirements later in the growing season.

Nutrient removal by crops

When grain is harvested from the paddock, nutrients are removed in the grain (Table 8). If, over time, more nutrients are removed (via grain) than are replaced (via fertiliser) then the fertility of the paddock will decline. This is not an immediate problem if the soil has ample nutrient reserves (inherent in the soil or from previous fertiliser applications), but if nutrient availability declines to the extent it limits plant growth, fertiliser applications will be required.[31]

31 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

Table 8: Nutrient removal via grain.

Grain	Kilograms (kg)					Grams (g)			
	N	P	K	S	Ca	Mg	Cu	Zn	Mn
Pulses									
Chickpea (desi)	33	3.2	9	2.0	1.6	1.4	7	34	34
Chickpea (kabuli)	36	3.4	9	2.0	1.0	1.2	8	33	22
Faba bean	41	4.0	10	1.5	1.3	1.2	10	28	30
Lentil	40	3.9	8	1.8	0.7	0.9	7	28	14
Lupin (sweet)	53	3.0	8	2.3	2.2	1.6	5	35	18
Lupin (white)	60	3.6	10	2.4	2.0	1.4	5	30	60
Field pea	38	3.4	9	1.8	0.9	1.3	5	35	14
Cereals									
Wheat	23	3.0	4	1.5	0.4	1.2	5	20	40
Barley	20	2.7	5	1.5	0.3	1.1	3	14	11
Oats	17	3.0	5	1.6	0.5	1.1	3	17	40

Source: Grain Legume Handbook for the Pulse Industry (2008), https://grdc.com.ay/Resources/Publications/2008/03/2008-Grains-Legume-Handbook

Actual values for nutrient removal can vary considerably. This is due to differences in soil fertility, varieties and seasons. For example, phosphorus per tonne removed by lentil grain can vary from a low 2.7 kg on low fertility soils to 5.1 kg on high fertility soils.

To prevent this, fertiliser inputs must be matched to expected yields and the nutritional status of the soil. The higher the expected yield, the higher the fertiliser input, particularly for the major nutrients, phosphorus, potassium and sulfur.

7.18 Nutrient budgeting

Nutrient budgeting is a simple way to calculate the balance between nutrient removal (via grain) and nutrient input (via fertiliser).

Table 9 shows an example of nutrient budgeting. The values used for nutrients removed are taken from Table 9.

Table 9: An example of nutrient budgeting.

Year	Crop	Yield (t/ha)	Nutrients removed (kg/ha)			
			N	P	K	S
2009	Faba bean	2.2	90	8.8	22	3.3
2010	Wheat	3.8	87	11.4	15	5.7
2011	Barley	4.2	84	11.3	21	6.3
2012	Chickpea	1.8	59	5.8	16	3.6
		Total	320	37.3	74	18.9

Year	Fertiliser	Rate	Nutrients applied (kg/ha)			
			N	P	K	S
2009	0 : 20 : 0	50	0	10	0	1
2010	18 : 20 : 0	70	12.6	14	0	1
2011	18 : 20 : 0	70	12.6	14	0	1
	Urea	60	27.6	0	0	0
2012	0 : 16 : 0 : 20	80	0	12.8	0	16
		Total	52.8	50.8	0	19
Balance			**–267.2**	**+13.5**	**–74**	**0**

From Table 9, a 2 t/ha crop of lentil will remove approximately 7.8 kg/ha of phosphorus. This then is the minimum amount of phosphorus that needs to be applied to maintain the soil phosphorus level. Higher quantities may be needed to build up soil fertility or overcome soil fixation of phosphorus.

As can be seen from Table 9, a sample nutrient budget, interpretation is required to establish the true situation:

Nitrogen: the nitrogen deficit of 267 kg needs to be countered by any nitrogen fixation that occurred.

This may have been 50 kg/ha per pulse crop; meaning the deficit might be more along the lines of 217 kg/ha (267 minus 50 kg/ha). Regardless, it still shows that the nitrogen status of the soil is decreasing.

Estimating nitrogen fixation is not an easy process because legumes vary in their capacity to fix nitrogen. There are inherent differences among the commonly grown legumes and external factors like moisture availability also impact nitrogen fixation.

Phosphorus: Table 9 shows a surplus of 13 kg of phosphorus. This surplus will be used by the soil in building phosphorus levels, hence increasing soil fertility.

Potassium: Reducing the level of potassium without replacing it with fertiliser is common practice on soils with inherently high levels of plant-available potassium. Historically this has been the case with heavier soils. However, many WA cropping soils (historically lighter, sandier soils) respond to annual applications of potassium;

MORE INFORMATION

For detailed information on nitrogen fixation go to: Inoculating Legumes: A Practical Guide. https://grdc.com.au/resources-and-publications/all-publications/bookshop/2015/07/inoculating-legumes on such soils fertiliser application of potassium should at least replace the potassium used by the crop.[32]

Sulfur: The sulfur applied as fertiliser matches sulfur removed by the crop.

Other nutrients, such as zinc and copper, should also be included in a nutrient balancing exercise.

Nutrient budgeting is a useful tool; however, it must be considered in conjunction with other nutrient management tools such as soil and tissue testing, soil type, soil fixation and potential yields.

As phosphorus is the basis of soil fertility and hence crop yields, all fertiliser regimes are based initially on the phosphorus requirement. Table 11 shows various fertilisers and the rates required to meet phosphorus requirements.

Table 10: Estimates of the amounts of nitrogen fixed annually by crop legumes in Australia.

Legume	% N fixed	Shoot dry matter (t/ha)	Shoot N (kg/ ha)	Root N (kg/ha)	Total crop N (kg/ ha)	Total N fixed[1] (kg/ha)
Lupin	75	5.0	125	51	176	130
Pea	66	4.8	115	47	162	105
Faba bean	65	4.3	122	50	172	110
Lentil	60	2.6	68	28	96	58
Soybean	48	10.8	250	123	373	180
Chickpea	41	5.0	85	85	170	70
Peanut	36	6.8	190	78	268	95
Mungbean	31	3.5	77	32	109	34
Navy bean	20	4.2	105	43	148	30

1 Total N fixed = percent N fixed x total crop N; Data sourced primarily from Unkovich *et al.*. 2010.

Source: E Drew et. al. (2012) Inoculating Legumes: A Practical Guide. Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/all-publications/bookshop/2015/07/inoculating-legumes

32 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

Table 11: Fertiliser application rate ready reckoner (all rates are read as kg/ha).

Phosphorus	Some of the fertilisers used on pulses															
	Superphosphate															
	Single 8.6% P		Gold Phos 10 18% P		Triple 20% P		6 : 16 : 0 : 10 Legume Special			10 : 22 : 0 MAP		18 : 20 : 0 DAP		0 : 15 : 0 : 7 Grain Legume Super	
	fert	S	fert	S	fert	S	fert	N	S	fert	N	fert	N	fert	S
10	116	13	50	5	45	0.7	62	4	6	46	5	50	9	69	5
12	140	15	67	7	60	0.9	75	4	8	55	6	60	11	83	6
14	163	18	78	8	70	1.1	87	5	9	64	6	70	13	97	7
16	186	20	89	9	80	1.2	99	6	10	73	7	80	14	110	8
18	209	23	100	10	90	1.4	112	6	11	82	8	90	16	124	9
20	223	25	111	11	100	1.5	124	7	12	91	9	100	18	138	10
22	256	28	122	12	110	1.7	137	8	14	100	10	110	20	152	11
24	279	31	133	13	120	1.8	149	8	15	110	11	120	22	166	12

Growers should always consult an agronomist when determining fertiliser applications for lentil.

7.19 Keys for successful uptake of nutrients by lentil

IN FOCUS

Both macronutrients and micronutrients are taken up (absorbed) by roots and require certain soil conditions for that to occur:

Soil must be sufficiently moist to allow roots to take up and transport the nutrients. Plants that are moisture stressed from either too little or too much moisture (saturation) can often exhibit deficiencies even though a soil test may show these nutrients to be adequate;

Soil pH influences the availability of most nutrients and must be within a range (6 to 8 in $CaCl_2$) for nutrients to be released from soil particles. On acid soils, aluminium and manganese levels can increase and may restrict plant growth, usually by restricting the rhizobia and so the plant's ability to nodulate; and soil temperature must lie within a certain range for nutrient uptake to occur.

Cold conditions can induce deficiencies such as zinc or phosphorus. The optimum range of temperature, pH and moisture can vary for different pulse crops. Thus, nutrients may be physically present in the soil, but not available to those plants. Knowledge of a soil's nutrient status (soil test) pH, texture, history, and moisture status are all very useful for predicting potential nutrient deficiencies. Tissue tests, later on, help to confirm the level of individual nutrients in the plant.