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GRDC GROWNOTES™

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHICKPEA

SECTION 5

NUTRITION AND FERTILISER

NUTRIENT TYPES | CROP REMOVAL RATES | IDENTIFYING NUTRIENT DEFICIENCIES | SOIL TESTING | PLANT AND/OR TISSUE TESTING FOR NUTRITION LEVELS | FERTILISER | NITROGEN | PHOSPHORUS | SULFUR | POTASSIUM | MICRONUTRIENTS | NUTRITIONAL DEFICIENCIES

FAQ

Nutrition and fertiliser

Key messages

- Incorrect levels of nutrients (too little, too much, or the wrong proportion) can cause nutritional problems.
- Today, the main method to maintain or restore soil nutrients and increase crop yields is the application of mineral fertilisers.
- A soil or plant tissue test will help to identify what nutrients are limiting yield or quality.
- Become familiar with plant and paddock symptoms of various nutritional deficiencies.
- If chickpea plants have effectively nodulated, they should not normally need N fertiliser.
- Phosphorus is the main nutrient of consideration. Trace elements zinc, manganese and iron are always important to production and quality but remain variable and as such should be evaluated by soil and plant tests, local experience and paddock trials.
- Molybdenum and cobalt are required for effective nodulation and should be applied as needed. Foliar sprays of zinc and manganese may be needed where deficiencies of these micronutrients are a known problem, in particular on high-pH soil types.

Incorrect levels of nutrients (insufficient, excess or disproportionate) can cause nutritional deficiencies or toxicities. If the condition is extreme, plants will show visible symptoms that can sometimes be identified. Visual diagnostic symptoms are readily obtained and they provide an immediate evaluation of nutrient status. Visual symptoms do not develop until a major effect on yield, growth or development has occurred; therefore, damage can be done before there is visual evidence of it.

Healthy plants are more able to ward off disease, pests, and environmental stresses and so achieve higher yield and better grain quality. [1] Ensuring adequate nutrition will assist the chickpea crop to generate dense uniform canopies, which deter aphids. [2]

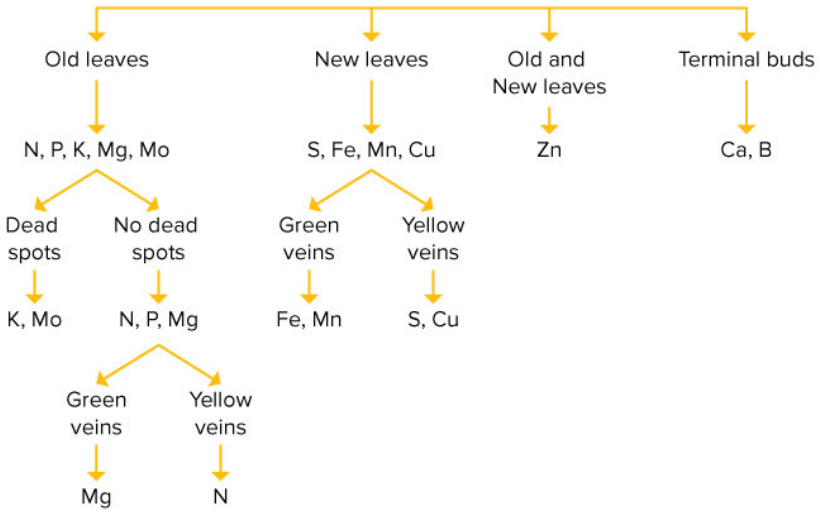

Figure 1: *Flow chart for the identification of deficiency symptoms.*

Source: T Reddy, G Reddi, Kalyani Publishers

1 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

2 A Verrell (2103) Wirus in chickpea in northern NSW 2012. GRDC Update Papers 26 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Virus-in-chickpea-in-northern-NSW-2012

In south-eastern Australia profitable grain production depends on applied fertilisers, particularly nitrogen (N), phosphorus (P) and to a lesser extent, potassium (K), sulfur (S), zinc (Zn), manganese (Mn) and copper (Cu).

The more attention paid to all of the activities that contribute to nutrient management (Figure 2), the better the outcome achieved from soil and plant testing. Testing may not provide a useful contribution if one or more of these steps is not done well.

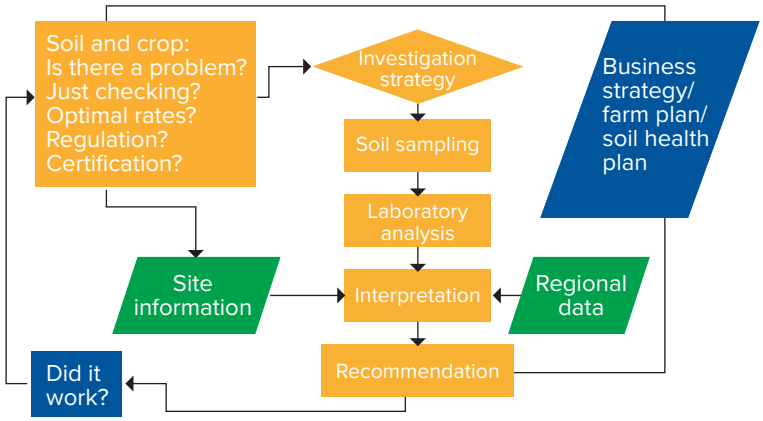

Figure 2: *Nutrient management flow chart.* [3]

5.1 Nutrient types

Plant nutrients are categorised as either macronutrients or micronutrients (also called trace elements). Macronutrients are those elements that are needed in relatively large amounts. They include N, P, and K, which are the primary macronutrients, with calcium (Ca), magnesium (Mg), and sulfur (S) considered as secondary. Higher expected yields of crops for grain or forage will place greater demand on the availability of major nutrients such as P, K, and S. Nitrogen, P, and at times S are the main nutrients commonly lacking in Australian soils. Others can be lacking under certain conditions. Keep in mind that each pulse type is different, with different requirements for nutrients and may display different symptoms of deficiency. A balance sheet approach to fertiliser inputs is often a good starting point when determining the amount and type (analysis) of fertiliser to apply. Other factors such as a soil test, paddock history, soil type, and personal experience are important inputs to the decision process. Tissue analysis can be helpful in identifying deficiencies once the crop is growing, and can assist in fine-tuning nutrient requirement even when deficiency symptoms are not visible. Micronutrients are those elements that plants need in small amounts, for example iron (Fe), boron (B), manganese (Mn), zinc (Zn), copper (Cu), chlorine (Cl), and Mo.

Both macro- and micronutrients are taken up by roots and certain soil conditions are required 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 has an effect on the availability of most nutrients and must be within a particular range for nutrients to be released from soil particles. On acid soils, Aluminium (Al) and Mn levels can become elevated and toxic to plants. Aluminium toxicity disrupts the structure and funtion of plant roots, presenting as stunted roots, limiting nutrient and moisture uptake. Aluminium will form a bond with available soil P making it unavailable to plants in the short to medium

3 GRDC (2013) Better fertiliser decisions for crop nutrition. GRDC Crop Nutrition Fact Sheet November 2013, http://grdc.com.au/Resources/Factsheets/2013/11/Better-fertiliser-decisions-for-crop-nutrition

term. Mn toxicity affects plant development with a range of symptoms including leaf yellowing and tissue death, mainly on older leaves. If Al and Mn levels increase, plant growth can be restricted, usually by limiting rhizobia and therefore the plant's ability to nodulate. Soil temperature must lie within a certain range for nutrient uptake to occur. Cold conditions can induce deficiencies of nutrients such as Zn or P. The optimum range of temperature, pH, and moisture can vary for different pulse species. Thus, nutrients may be physically present in the soil, but not available to those particular plants. Knowledge of a soil's nutrient status (soil test) pH, texture, history, and moisture status can be very useful for predicting which nutrients may become deficient. Tissue tests can help to confirm the plant nutrient status. [4]

5.2 Crop removal rates

If the nutrients (P, N, Zn, etc.) removed as grain from the paddock are not replaced, then soil fertility and crop yields will fall. This means that fertiliser inputs must be matched to expected yields and soil type. The higher the expected yield, the higher the fertiliser input, particularly for the major nutrients P, K, and S. The nutrient removal per tonne (t) of grain of the various pulses is shown in Table 1. Actual values may vary by 30%, or sometimes more, because of differences in soil fertility, varieties, and seasons. For example, P removed by 1 t of faba bean grain can vary from a low 2.8 kg on low-fertility soils to 5.4 kg on high-fertility soils. From the table, a 2 t/ha crop of chickpeas will on average remove ~6.5 kg/ha of P. This then is the minimum amount of P that needs to be replaced. Higher quantities may be needed to build up soil fertility or overcome soil fixation of P.

Table 1: *Nutrients removed by one tonne of chickpea grain.*

Chickpea	Kilograms (kg)				Grams (g)				
	N	P	K	S	Ca	Mg	Cu	Zn	Mn
Desi	33	3.2	9	2.0	1.6	1.4	7	34	34
Kabuli	36	3.4	9	2.0	1.0	1.2	8	33	22

Source: Pulse Australia.

Soil types do vary in their nutrient reserves. For example, most black and red soils have sufficient reserves of K to grow many crops. However, the light, white sandy soils, which, on soil test, have <50 µg/g (ppm) (bicarbonate test) of K, will respond to applications of K fertiliser. Other soils may have substantial nutrient reserves that vary in availability during the growing season or are unavailable due to the soil pH. This can often be the case with micronutrients. Foliar sprays can be used in these cases to correct any micronutrient deficiencies. [5]

5.2.1 Nutrient budgeting

When grain is harvested from the paddock, nutrients are removed in the grain. If, over time, more nutrients are removed than are replaced (via fertiliser), then the fertility of the paddock will fall. Nutrient budgeting is a simple way to calculate the balance between nutrient removal (via grain) and nutrient input (via fertiliser).

Table 2 uses standard grain nutrient analyses from Table 1. For a more accurate guide to nutrient removal, use analysis of grain grown on your farm. A more complete picture emerges when several years of a rotation are budgeted.

4 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

5 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 2: *An example of nutrient budgeting.* [6]

Year	Crop	Yield (t/ha)	Nutrients removed (kg/ha)			
			N	P	K	S
2006	Faba bean	2.2	90	8.8	22	3.3
2007	Wheat	3.8	87	11.4	15	5.7
2008	Barley	4.2	84	11.3	21	6.3
2009	Chickpea	1.8	59	5.8	16	3.6
		Total	320	37.3	74	18.9
Year	**Fertiliser**	**Rate (t/ha)**	**Nutrients applied (kg/ha)**			
			N	P	K	S
2006	0 : 20 :0 (NPK)	50	0	10	0	1
2007	18 : 20 :0 (NPK)	70	12.6	14	0	1
2008	18 : 20 :0 (NPK)	70	12.6	14	0	1
	Urea	60	27.6	0	0	0
2009	0 : 16 :0 :20 (NPK)	80	0	12.8	0	16
		Total	52.8	50.8	0	19
Balance			-267.2	+13.5	-74	0

As can be seen from Table 2, a simple nutrient budget, some interpretation of a nutrient budget is needed:

- Nitrogen: The deficit of 267 kg needs to be countered by any N fixation that occurred. This may have been 50 kg/ha per legume crop. It still shows that the N status of the soil is falling and that it should be increased by using more N in the cereal phase. Estimating N fixation is not easy. One rule to use is 20 kg of N is fixed per tonne of plant dry matter at flowering.
- Phosphorus: The credit of 13 kg will be used by the soil in building P levels, hence increasing soil fertility. No account was made for soil fixation of P.
- Potassium: Some Australian cropping soils (usually white sandy soils) are showing responses to K, and applications should be considered at least to replace the K used by the crop.
- Sulfur: Crop removal of S may exceed inputs.

Other nutrients such as Zn and Cu can also be included in a nutrient-balancing exercise. This is a useful tool for assessing the nutrient balance of a cropping rotation; however, it needs to be considered in conjunction with other nutrient-management tools such as soil and tissue testing, soil type, soil fixation, and potential yields. Because P is the basis of soil fertility and, hence, crop yields, all fertiliser programs are built on the amount of P needed. Table 3 shows the required P rates and the rates of various fertilisers needed to achieve this. Many fertilisers are available to use on pulses; for the best advice, check with your local fertiliser reseller or agronomist.

6 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 3: *Fertiliser application rate ready-reckoner (all rates are kg/ha) for some of the fertilisers used on pulses.*

P	Single 8.6% P		Superphosphate 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

There is a trend to using 'starter' fertilisers such as mono- and di-ammonium phosphate (MAP and DAP) on pulses. Some growers are concerned that using N on their pulse crop will affect nodulation. This is not the case with the low rates of N supplied by MAP or DAP. A benefit of using the starter N is that early plant vigour is often enhanced, and on low fertility soils, yield increases have been gained. [7]

5.3 Identifying nutrient deficiencies

Many nutrient deficiencies may look similar. To identify deficiencies:

- Know what a healthy plant looks like in order to recognise symptoms of distress.
- Determine what the affected areas of the crop look like. For example, are they discoloured (yellow, red, brown), dead (necrotic), wilted or stunted?
- Identify the pattern of symptoms in the field (patches, scattered plants, crop perimeters).
- Assess affected areas in relation to soil type (pH, colour, texture) or elevation.
- Look at individual plants for more 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 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. For instance, molybdenum (Mo) is required by pulses to complete the process of nitrogen (N) fixation and the symptoms present as nitrogen deficiency. [8]

See sections below for specific symptoms of each nutrient deficiency.

5.3.1 Tests for nutrient deficiency

It is commonly believed that a soil or plant tissue test will show how much nutrient is required by the plant. This is not so. A soil or plant tissue test will only help to identify what is missing or in excess. A soil test will only show that at a certain soil concentration, whether the plant is likely or unlikely to respond to that nutrient. These tests are specific for both soil type and plant being grown (Table 4).

7 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

8 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Experience suggests that the only worthwhile soil tests will be for P, K, organic matter, soil pH, and soil salt levels. An S test has now been developed. Pulse crops can have different requirements for K, hence different soil test K critical levels.

Table 4: *Adequate levels for various soil test results.*

Nutrient	**Test Used**		
Phosphorus			
	Colwell	**Olsen**	
Sand	20-30	10-15	
Loam	25-35	12-17	
Clay	35-45	17-23	
Potassium			
	Bicarb.	**Skene**	**Exchangeable K**
Sand	50	50-100	Not applicable
Other soils	100	-	0.25 m.e/100 g
Sandy loam	-	-	-
Faba bean	100-120	-	-
Field pea	70-80	-	-
Lupin	30-40	-	-
Canola	40	-	-
Cereals	30	-	-
Sulfur			
	KCl		
Low	5µg/g (ppm)		
Adequate	8µg/g		

Source: Grain Legume Handbook (2008).

5.4 Soil testing

Key points

- A range of soil test values used to determine if a nutrient is deficient or adequate is termed a critical range.
- Revised critical soil test values and ranges have been established for combinations of nutrients, crops, and soil.
- Nutrient sufficiency is indicated if the test value is above the critical range and therefore there is not likely to be a crop yield response to added nutrients.
- Where the soil test falls below the critical range there is likely to be a crop yield response from added nutrients.
- Soil sampling to greater depth is considered important for more mobile nutrients (N, K, and S) as well as for pH and salinity.
- Use local data and support services to help integrate critical soil test data into profitable fertiliser decisions.

Accurate soil tests allow small landholders to maximise the health of their soils and make sound decisions about fertiliser management to ensure crops and pastures are as productive as possible. Up-to-date critical soil test values will help improve test interpretation to inform better fertiliser decisions. Identifying potential soil limitations

enables landholders to develop an action plan (such as an appropriate fertiliser program) to reduce the potential of 'problem' paddocks. [9]

Fertiliser is a major variable cost for grain growers. Crop nutrition is also a major determinant of profit. Both under and over-fertilisation can lead to economic losses due to unrealised potential or wasted inputs.

Before deciding how much fertiliser to apply, it is important to understand the quantities of available nutrients in the soil and where they are located in the soil profile. It is also important to consider whether the fertiliser strategy aims to build, maintain or mine the soil reserves of a particular nutrient. Soil test critical values indicate if the crop is likely to respond to added fertiliser, but these figures do not predict optimum fertiliser rates. Soil test results can be compared against critical nutrient values and ranges, which indicate nutrients that are limiting or adequate. When considered in combination with information about potential yield, last year's nutrient removal and soil type, soil tests can help in making fertiliser decisions.

In the southern region either the Colwell P or DGT P methods are used to assess the availability of P in a soil sample to a crop. It is recommended that a PBI measure accompanies the Colwell P value in order to obtain an indication of the critical Colwell P value as these can vary with different soil types (Table 5). DGT has shown to provide an improve estimate of P availability on calcareous soils and preliminary data also suggests this test may also be useful on acidic soil types with high PBI values. Critical values are freely available from accredited lab providers or from the soil quality factsheet. [10]

Principal reasons for soil testing for nutrition include:

- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity), and salinity, which affect the availability of nutrients to crops;
- zoning paddocks for variable application rates;
- comparing areas of varying production; and
- as a diagnostic tool, to identify reasons for poor plant performance.

Soil acidity or alkalinity can influence the amount of nutrients available to plants. Table 5 demonstrates nutrient constraints based on soil pH.

9 DAFWA. (2016). Soil sampling and testing on a small property. https://www.agric.wa.gov.au/soil-productivity/soil-sampling-and-testing-small-property

10 GRDC (2016) Monitoring of soil phosphorus, potassium and sulfur. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Monitoring-of-soil-phosphorus-potassium-and-sulfur

Table 5: *Soil classifications for pH (1:5 soil:water).* [11]

Increasing acidity						**Increasing alkalinity**
Acidic				Neutral	Alkaline	
3	**4**	**5**	**6**	**7**	**8**	**9** **10**
Toxicity of :						Toxicity of :
Aluminium (Al)			**Ideal pH Range** for plant growth			Sodium (Na)
Manganese (Mn)						Boron (Bo)
Iron (Fe)						Bicarbonate (HCO3)
Deficiency of:						Deficiency of:
Magnesium (Mg)						Fe
Calcium (Ca)						Zinc (Zn)
Potassium (K)						Mn
Phosphorus (P)						Copper (Cu)
Molybdenum (Mo)						P

5.4.1 Types of test

Appropriate soil tests for measuring soil extractable or plant available nutrients are:

- bicarbonate extractable P (Colwell-P) or DGT for P;
- bicarbonate extractable K (Colwell-K);
- KCl-40 extractable S;
- 2M KCl extractable inorganic N, which provides measurement of nitrate-N and ammonium-N.

For determining crop N requirement, soil testing is unreliable. This is because soil nitrogen availability and crop demand for nitrogen are both highly influenced by seasonal conditions.

Other measurements that aid the interpretation of soil nutrient tests include soil pH, percentage of gravel in the soil, soil carbon/organic matter content, P sorption capacity [currently measured as Phosphorus Buffering Index (PBI)], electrical conductivity, chloride and exchangeable cations (CEC) including aluminium.

Depth for nutrient sampling

The Better Fertiliser Decisions for Cropping (BFDC) project has highlighted that deeper soil sampling provides more appropriate critical soil values and ranges for many soil types. Soil sampling depth for nutrient analysis is currently 0 to 10 centimetres. The 0–10 cm soil layer was originally chosen because nutrients, especially P, and plants roots are concentrated within this layer. Increasingly, there is evidence of the need to assess production constraints, including acidity, in both the surface soil and subsoil layers.

The importance of subsoil K and S contributions to plant nutrient uptake has also been known for a long time. To obtain more comprehensive soil data, including nutrient data, sampling to 30 cm should be considered, providing there are no subsoil constraints (Photo 1). Collecting deeper soil samples does raise issues of logistics and cost, which should be discussed with soil test providers. One suggested approach is to run a comprehensive suite of soil tests on all 0–10 cm samples and only test for N, K, S, and salinity in 10–30 cm samples. On sands, P can also be tested for at depth.

11 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Note that pH samples need to be taken at 10 cm increments to depth. If sampling to 30 cm, the 0–10 cm, 10–20 cm and 20–30 cm soil layer samples should be tested for pH so that soil acidity can be better understood.

Photo 1: *Nutrients, even relatively immobile ones such as phosphorus (P), can move down the profile in sandy soil, so testing nutrient reserves to depth can be useful.*

Source: GRDC, Photo: Gavin Sarre.

Collecting soil samples for nutrient testing

The greatest source of error in any soil test comes from the soil sample. Detailed sampling instructions are usually provided in soil test kits. The following information is provided as a reference only.

When sampling the 0–10 cm soil layer, 20 to 30 cores per site are required, while for the 10–30 cm soil layer, 8 to 10 cores per site are required. Cores per sample from a uniform zone should be bulked, mixed and sub-sampled for testing. For pH, it is often more useful to see how the figures vary within the paddock or across soil types—therefore, sampling will always be less than ideal. For pH, 8 to 10 cores bulked from six locations in a paddock is usually adequate.

To ensure that a sample is representative:

- check that the soil type and plant growth where the sample is collected are typical of the whole area;
- avoid areas such as stock camps, old fence lines, and headlands;
- ensure that each sub-sample is taken to the full sampling depth;
- do not sample in very wet conditions;
- avoid shortcuts in sampling such as taking only one or two cores, a handful, or a spadeful of soil; and
- avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers or other sources of nutrients such as sunscreen, containing zinc.

Critical values and ranges

A soil test critical value is the soil test value required to achieve 90 per cent of crop yield potential. The critical range around the critical value indicates the reliability of the test. The narrower the range, the more reliable the data (Table 6).

Table 6: *Summary table of critical values (mg/kg) and critical ranges for the 0-10 cm sampling layer.*

Soil Test	Crop	Soil Type*	Critical Values (mg/kg)	Critical range (mg/kg)
Colwell-[b]	Wheat and barley	Vertosol	17	12-25
		Chromosol/sodosol	22	17-28
		Brown/red chromosol	25	18-35
		Calcarosol	34	26-44
	Barley	Ferrosols	76	46-130
	Canola	All soils	18	16-19
	Field Pea	All soils	24	21-28
Colwell-K	Wheat	Chromosols	40	35-45
		Brown ferrosols	64	57-70
		Kandosols	49	45-52
		Tenosols	41	32-52
	Canola	All soils	45	43-47
	Lupin	Tenosols (WA data)	24	22-27
KCl-40 S+	Wheat	Chromosols/kandosols/ Sodosols/tenosols/ Vertosols	4.5	3.2-6.4
	Canola	NSW data (0 to 15 cm)	8.6	4.8-15.0
		NSW data (0 to 60 cm)	31	25-39

Source: GRDC.

The critical value indicates if a nutrient is likely to limit crop yield based on whether the value is greater than or less than the upper or lower critical range value (Figure 3). If the soil test value is less than the lower limit, the site is likely to respond to an application of the nutrient. For values within the range, there is less certainty about whether a response will occur. In this case, growers have to exercise judgement about the costs and benefits of adding fertiliser in the forthcoming season, versus those associated with not applying. If the soil test is above the critical range, fertiliser is applied only to maintain soil levels or to lower the risk of encountering deficiency. The larger the range around the critical value, the lower the accuracy of the critical value. [12]

12 GRDC. (2014). Crop Nutrition Fact Sheet – Western Region. Soil Testing for crop nutrition. www.grdc.com.au/GRDC-FS-SoilTestingW

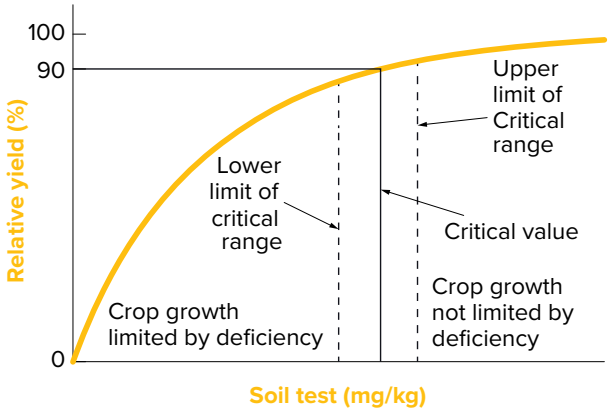

Figure 3: *Generalised soil test response calculation curve. A generalised soil test–crop response relationship defining the relationship between soil test value and per cent grain yield expected. A critical value and critical range are defined from this relationship. The relative yield is the unfertilised yield divided by maximum yield, expressed as a percentage. The BFDC Interrogator fits these curves and estimates critical value and critical range. Normally 90% of maximum yield is used to define the critical value but critical values and ranges at 80% and 95% of maximum yield can also be produced.*

Source: GRDC.

MORE INFORMATION

GRDC Soil testing for crop nutrition – Southern Region Fact sheet.

5.4.2 Southern Australian Soil Quality Program

Key Points

- Soil quality is currently being measured in grain-producing areas across Australia.
- This monitoring program and associated website www.soilquality.org.au provide the Australian grains industry with a unique resource on soil quality including soil biology, chemistry, and physics.
- Each grower's soil quality information is housed on the soil quality website and workshops provide growers with training to access and interpret this information to support improved soil management.

Soilquality.org.au provides an interactive resource to the Australian grains industry on soil quality, including soil biology as well as soil chemistry and physics. The web site allows growers to benchmark their paddocks against values for their local catchment and region as well as against expert opinion. This information aids growers to determine if they are heading in the right direction with their systems and practices, and supports growers to improve soil management practices. The Soil Quality Monitoring Program and the web site www.soilquality.org.au are expanding to include grain producing areas across Australia. This will give growers across Australia access to regionally specific data on soil biological, chemical, and physical constraints to production. This will aid the Australian grains industry to make better management decisions. [13]

5.5 Plant and/or tissue testing for nutrition levels

Plant tissue testing can also be used to diagnose a deficiency or monitor the general health of the pulse crop. Plant tissue testing is most useful for monitoring crop health, because by the time noticeable symptoms appear in a crop the yield potential can be markedly reduced.

13 Soilquality.org. Southern Australian Soil quality program. http://www.soilquality.org.au/factsheets/s-a-soil-quality-program

Why measure nutrients in plant tissues?

Of the many factors affecting crop quality and yield, soil fertility is one of the most important. It is fortunate that producers can manage fertility by measuring the plant's nutritional status. Nutrient status is an unseen factor in plant growth, except when imbalances become so severe that visual symptoms appear on the plant. The only way to know whether a crop is adequately nourished is to have the plant tissue analysed during the growing season.

What plant tissue analysis shows

Plant tissue analysis shows the nutrient status of plants at the time of sampling. This, in turn, shows whether soil nutrient supplies are adequate. In addition, plant tissue analysis will detect unseen deficiencies and may confirm visual symptoms of deficiencies. Toxic levels also may be detected. Though usually used as a diagnostic tool for future correction of nutrient problems, plant tissue analysis from young plants will allow a corrective fertiliser application that same season. A plant tissue analysis can pinpoint the cause, if it is nutritional. A plant analysis is of little value if the plants come from fields that are infested with weeds, insects, and disease organisms; if the plants are stressed for moisture; or if plants have some mechanical injury. The most important use of plant analysis is as a monitoring tool for determining the adequacy of current fertiliser practices. Sampling a crop periodically during the season or once each year provides a record of its nutrient content that can be used through the growing season or from year to year. With soil test information and a plant analysis report, a producer can closely tailor fertiliser practices to specific soil-plant needs.

DO'S

- Sample the correct plant part at the specified time or growth stage.
- Use clean plastic disposable gloves to sample to avoid contamination.
- Sample tissue (e.g. entire leaves) from vigorously growing plants unless otherwise specified in the sampling strategy.
- Take sufficiently large sample quantity (adhere to guidelines for each species provided).
- When troubleshooting, take separate samples from good and poor growth areas.
- Keep samples cool after collection.
- Refrigerate or dry if samples can't be dispatched to the laboratory immediately, to arrive before the weekend.
- Generally sample in the morning, while plants are actively transpiring.

DON'TS

- Avoid spoiled, damaged, dead or dying plant tissue.
- Don't sample plants stressed by environmental conditions.
- Don't sample plants affected by disease, insects or other organisms.
- Don't sample soon after applying fertiliser to the soil or foliage.
- Avoid sample contamination from dust, fertilisers, and chemical sprays, as well as perspiration and sunscreen from hands.
- Avoid atypical areas of the paddock, e.g. poorly drained areas.
- Do not sample plants of different vigour, size, and age.
- Do not sample from different cultivars (varieties) to make one sample.
- Don't collect samples into plastic bags as this will cause the sample to sweat and hasten its decomposition.
- Don't sample in the heat of the day, i.e. when plants are moisture stressed.
- Don't mix leaves of different ages.

Chickpeas should be sampled during the pre-flowering growth stage, with 25–40 samples of the plant collected (Figure 4). [14]

Figure 4: *Collect samples from the whole tops of chickpea plants.*

Source: Spectrum analytic.

Several companies perform plant tissue analysis and derive accurate analytical concentrations; however, it can be difficult to interpret the results and determine a course of action. As with soil tests, different plants have different critical concentrations for a nutrient. In some cases, varieties can differ in their critical concentrations. Table 7 lists the plant analysis criteria for chickpeas. These should be used as a guide only. Care should be taken to use plant tissue tests for the intended purpose.

Table 7: *Critical nutrient levels for chickpea at flowering.*

Nutrient	Plant Part	Critical Range
Nitrogen (%)	Whole shoot	2.3
Phosphorus (%)	Whole shoot	0.24
Potassium (%)	Whole shoot	2.1
Potassium (%)	Youngest mature leaf	1.5
Sulfur (%)	Whole shoot	0.15-0.20
Boron (mg/kg)	Whole shoot	40
Copper (mg/kg)	Whole shoot	3
Zinc (mg/kg)	Whole shoot	12

Most tests diagnose the nutrient status of the plants only at the time they are sampled; they cannot reliably indicate the effect of a particular deficiency on grain yield. Another strategy is to tissue-test a number of paddocks and farms. If there is concern over poor-performing areas, the tissue test can be used to diagnose the potential nutrient deficiency. The critical range (Table 7) can be difficult to use. Wide variations in tissue test results can be due to stress such as frost or waterlogging or even more subtle factors such as solar radiation or time of day of sampling. Although a valuable tool, tissue testing must be used as only one part of an integrated nutrition program. [15]

14 Back Paddock SoilMate. Guidelines for sampling plant tissue for annual cereal, oilseed and grain legume crops. http://www.backpaddock.com.au/assets/Product-Information/Back-Paddock-Sampling-Plant-Tissue-Broadacre-V2.pdf?phpMyAdmin=c59206580c88b2776783fdb796fb36f3

15 Pulse Australia (2013) Northern chickpea best management practices training course manualnd grain legume crops. Limited.

5.6 Fertiliser

Fertiliser recommendations for chickpeas, as with most pulses, tend to be generic, with an over-reliance on the recommendation of MAP-based starter fertilisers across nearly all situations. This is often driven by convenience and availability, rather than meeting the specific nutrient requirements of the crop.

Fertiliser recommendations need to be more prescriptive, and should take into account:

- soil type
- rotation (fallow length and impact arbuscular mycorrhizal fungi (AMF) levels)
- yield potential of the crop
- plant configuration (row spacing, type of opener and risk of 'seed burn')
- soil analysis
- effectiveness of inoculation techniques.

Molybdenum and cobalt (Co) are required for effective nodulation and should be applied as needed. Soil P levels influence the rate of nodule growth. The higher the P level, the greater is the nodule growth. [16]

Nitrogen fertilisers in small amounts (5–15 kg N/ha) are not harmful to nodulation and can be beneficial by extending the early root growth to establish a stronger plant. MAP or DAP fertilisers can be used.

However, excessive amounts of N will restrict nodulation and reduce N fixation.

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

Acid fertilisers include:

- superphosphates (single, double, triple)
- fertilisers with Cu and/or Zn
- MAP, also known as 11 : 23 : 0 and Starter 12

Neutral fertilisers include:

- 'Super lime'

Alkaline fertilisers include:

- DAP also known as 18 : 20 : 0
- starter NP
- lime[17]

5.6.1 Fertiliser toxicity

All pulses can be affected by fertiliser toxicity. Drilling 10 kg/ha of P with the seed in 18 cm row spacing through 10 cm points rarely caused problems. However, with the changes in sowing techniques to narrow sowing points, minimal soil disturbance, wider row spacing, and increased rates of fertiliser (all of which concentrate the fertiliser near the seed in the seeding furrow), the risk of toxicity is higher.

The effects are also increased in highly acidic soils, in sandy soils, and where moisture conditions at sowing are marginal. Drilling concentrated fertilisers to reduce the product rate per hectare does not reduce the risk.

The use of starter N, e.g. DAP, banded with the seed when sowing pulse crops has the potential to reduce establishment and nodulation if higher rates are used. On sands, up to 10 kg/ha of N at 18 cm row spacing can be safely used. On clay soils, do not exceed 20 kg/ha of N at 18 cm row spacing.

VIDEOS

1. Improving phosphate use efficiency.

16 Lamb, J., & Poddar, A. (1992). Grain legume handbook. South Australian Pea growers Co-operative Ltd., Riverton, South Australia.

17 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Deep banding of fertiliser is often preferred for lupins— otherwise broadcasting and incorporating, drilling pre-seeding or splitting fertiliser applications so that a lower P rate or no P is in contact with the seed. [18]

5.7 Nitrogen

Key points

- If chickpea plants have effectively nodulated, they should not normally need N fertiliser.
- Nitrate (NO^3-) is the highly mobile form of inorganic nitrogen in both the soil and the plant (Figure 5).
- Sandy soils in high rainfall areas are most susceptible to nitrate loss through leaching.
- Soil testing and nitrogen models will help determine seasonal nitrogen requirements. [19]

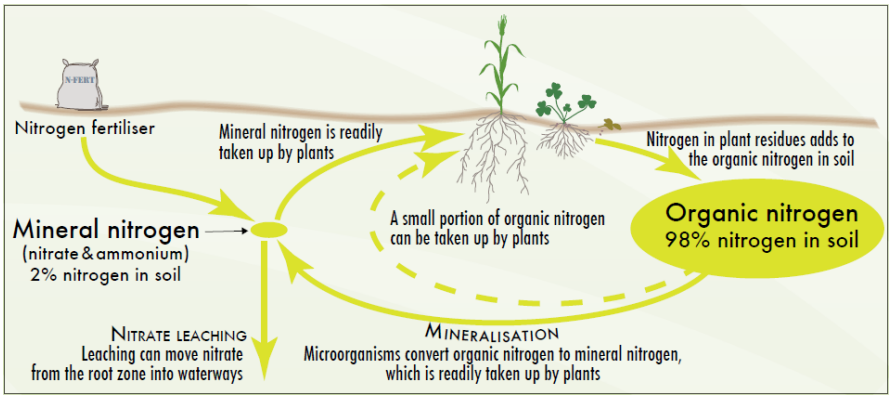

Figure 5: *The soil nitrogen cycle showing the role of mineralisation in making organic nitrogen in soil available for plants to take up.*

Source: Soilquality.org

If chickpea plants have effectively nodulated, they should not normally need N fertiliser (Table 8). Some situations where N fertiliser may warrant consideration include:

- where the grower is unwilling to adopt recommended inoculation procedures
- late or low-fertility planting situations where rapid early growth is critical in achieving adequate height and sufficient biomass to support a reasonable grain yield.

If available soil N is low or sowing is late then "starter" N rates of 5–10 kg/ha may be beneficial. [20] It would be uneconomic to apply N fertiliser rates equivalent to that which would otherwise be fixed by the nodulated chickpea crop.

VIDEOS

2. GCTV14: Nitrogen deficiency.

18 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

19 Soilquality.org. Nitrogen – Western Australia. http://www.soilquality.org.au/factsheets/mineral-nitrogen

20 Pulse Australia. Chickpeas in South Australia and Victoria. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpeas-SA-Vic.pdf

Table 8: *Nitrogen balance for chickpeas. Grain harvest index (HI) is the grain yield as a percentage of total shoot dry matter production (average ~40%). Chickpea grain contains 3234 kg N/t.* [21]

Total plant dry matter (t/ha)	Total shoot dry matter yield (t/ha)	Grain yield (t/ha) 40% HI	Total crop N requirement (2.3% N) (kg/ha)	N removal in grain (kg/ha)
1.75	1.25	0.5	40	17
3.50	2.50	1.0	80	33
5.25	3.75	1.5	120	0
7.00	5.00	2.0	160	66
8.75	6.25	2.5	200	83
10.50	7.50	3.0	240	100

IN FOCUS

Effects of below-ground nitrogen on N balances of field-grown faba beans, chickpeas, and barley

The objectives of this study were to quantify below-ground nitrogen (BGN) of rainfed faba beans, chickpeas, and barley and to use the values to determine N balances for the three crops. The BGN fraction of legumes in particular represents a potentially important pool of N that has often been grossly underestimated or ignored in calculating such balances.

The inclusion of BGN in the budgets increased N balances by 38 kg N/ha to +36 kg N/ha for faba beans and by 93 kg N/ha to +94 kg N/ha for chickpea. As there was no external (N_2 fixation) input of N to barley, the inclusion of BGN made no difference to the N balance of the crop of 74 kg N/ha. Such values confirm the importance of BGN of N_2-fixing legumes in the N economies of cropping systems. [22]

Factors influencing nitrogen supply from soils and stubbles

Nitrogen is the key major nutrient influencing crop production in Australian agricultural systems, and maintaining a close balance between inputs and outputs as well as better synchronization between N supply and plant demand is the role of soil management, fertiliser, crop residues, and crops.

Fertiliser N use in Australia increased at an annual rate of approximately 14% compared to that in 1992, which is not only considered economically unsustainable but also environmentally undesirable.

Nitrogen mineralized from soil organic matter and crop residues contributes to a large part of crop N requirements in the rainfed cropping regions across southern Australia. For example, in the year of application, fertiliser N contributes approximately 20–40% of the total N supply of wheat. Soil N supply comes from soil organic matter and recent crop residues and the rate of supply is influenced by the soil biological capacity and modulated by management and environmental factors.

The nitrogen mineralization potential of the top 10 cm soils generally ranges from 10–35 kg N/ha/season in sandy, 25–70 kg N/ha/year in clay and loam soils, and 30–100 kg N/ha/year in red brown earth soils.

The magnitude of soil biological processes and their impact within the farming system varies seasonally due to the variation in the time of their occurrence relative to the

21 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

22 Khan, D. F., Peoples, M. B., Schwenke, G. D., Felton, W. L., Chen, D., & Herridge, D. F. (2003). Effects of below-ground nitrogen on N balances of field-grown fababean, chickpea, and barley. Crop and Pasture Science, 54(4), 333-340.

crop growth and demand. The effect of soil organisms involved in N mineralisation can be seen in both the off-season (fallow) and in-crop season (Figure 6). Nitrogen mineralised during the off-season may accumulate and/or be lost through leaching, denitrification or weed uptake, whereas the N mineralised during the growing season in the rhizosphere may be utilised immediately by the crop. In a farming system, factors influencing nutrient mineralisation–immobilisation processes need to be understood in order to synchronise nutrient availability to plant needs and also to reduce nutrient losses. Additionally, critical periods of biological activity must be taken into consideration to optimise management strategies that help synchronise N supply to availability to crops.

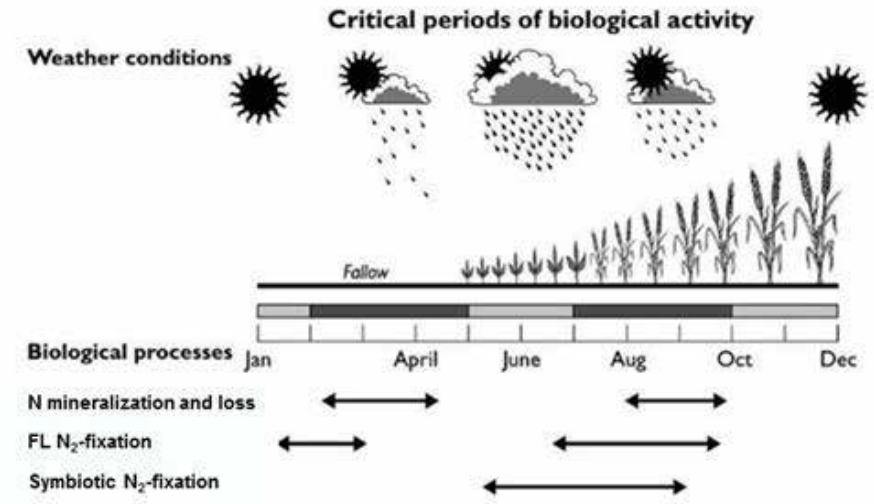

Figure 6: *A conceptual diagram showing functionally important periods for different N-cycling biological processes and their impact within the farming systems in Australian winter-cropping growing regions.*

Source: GRDC.

Decomposition and N mineralization

In low-fertility Australian agricultural soils, crop residues are one of the major sources of carbon (C) for soil biota and retention of stubble after harvest contributes to the conservation of nutrients taken up by the plant within the cropping system. A large portion of N used by crops is mineralised from previous crop and pasture residues through the activity of soil microorganisms (microbial biomass, MB). Decomposition of crop residues is mainly a biological process involving diverse groups of microbial communities and facilitated by the activity of soil fauna. Land use changes from mixed farms where crop rotation with legume pastures was common to continuous cereal cropping generally resulted in a decline in crop residue based N mineralisation. The decline occurred mainly through altered crop residue quality, e.g. wider C:N ratio (100:1) cereal residues replacing N-rich legume residues (15 to 25:1). It is considered that crop residues with a C:N ratio >22:1 generally result in immobilisation (tie-up) of mineral N in microbial biomass. The rate and timing of availability of nutrients from stubble to the following crops is determined by the rate of decomposition and immobilisation (tie-up) by soil microorganisms (N in microbial biomass; MB-N). The amount of N in microbial biomass varies with soil type, crop rotation, tillage, and other management practices that can influence microbial populations (Table 9). In southern Australian cropping regions, the effect of loss of nutrients from stubble removal may be greater than the temporary tie-up of the nutrients during decomposition when retained. However, the scale of these effects vary depending upon stubble load, time and type of burning and tillage.

Table 9: *Amount of nitrogen in microbial biomass and the soil N supply potential as influenced by soil type.*

Location	Soil type	Microbial biomass (kg N/ha)	N supply potential (kg N/ha)**
Waikerie/ Karoonda,SA	Sand and sandy loam	25–45	10–35
Streaky Bay, SA	Calcarosol	30–60	15–50
Kerrabee, NSW	Loam	60–75	35–50
Temora, NSW	Red earth	75–105	50–100
Rutherglen, Vic	Red brown earth	50–100	30–100
Leeton/Warialda, NSW	Clay	50–110	25–75

** N supply potential is calculated from N in MB plus N mineralization measured in a lab-incubation assay.
Source: GRDC.

Stubble retention can provide benefits through changes in soil's physical, chemical, and biological properties. However, the selection of stubble management strategy would have a substantial impact on the potential benefits to be gained from the activity of soil biota in their role in carbon turnover, nutrient mineralisation, and subsequent availability of nutrients to crops. For example, tillage practices accelerate the decomposition and microbial turnover resulting in quick accumulation of mineral N, especially in soils with lower microbial biomass levels. In addition, research from Victoria and South Australia (SA) has shown that tillage can disrupt the linkages between the activity of microbes processing organic N and those related to fertiliser and mineral N transformations influencing the rate of release and accumulation of mineral N in soil. This means strategic tillage practices could be developed to manipulate N release and losses (especially from legume residues), for example to synchronise the release of N to plant demand and avoid losses through leaching and denitrification.

Nitrogen released during decomposition and soil organic matter turnover is rapidly assimilated by MB which is subsequently released through microbial turnover and microbe-fauna interactions. Results from field experiments in SA indicated that in the sandy soils in the Mallee with lower levels of MB, there can be substantial movement (leaching) of mineral N (25–50 kg N/ha; $P < 0.05$) down the soil profile following summer rainfall. Retention of stubble, which generally increases the amount of MB, can therefore arrest the leaching of mineral N to lower depths.

Research at Karoonda in SA, on a dune-swale landscape, has shown that plant type (e.g. wheat, cereal rye, canola, or pasture) can cause large changes in the functional diversity of microorganisms, i.e. microbial communities involved in various biological functions including N cycling processes. Thus, in a crop rotation, such changes coupled with differences in the quantity and quality of organic residues (tops and roots) can significantly modify the N mineralisation-immobilisation processes and availability of N. The magnitudes of these effects vary with soil type and region, which needs to be considered when designing fertiliser N management strategy in a cropping sequence.

Nitrogen fixation—free-living N fixation

Biological nitrogen fixation, by symbiotic and free-living (FL) bacteria can provide economic and environmental sustainability to N management in Australian agriculture. Free living N fixation refers to N fixation by bacteria growing independently in soil or in close association with plant roots where symbiotic N fixation occurs through legume-rhizobia interaction in nodules. Research has shown that communities of free-living and endophytic N-fixing bacteria have been found in association with cereal crops, grasses (including summer active perennial pastures) and non-leguminous plants. With the increased adoption of intensive cropping and area under consecutive cereal crops (>50%), FL-N fixation has the potential to make a major contribution to N requirements in cereal crops.

Additionally, current conservation farming systems support a habitat that promotes activity of FL-N fixing (nifH gene harbouring) bacterial communities both during off-season and in crop, i.e. increased microsites with C availability, wide C/N ratio etc. Improvements in FL-N fixing capacity in soils can provide multiple benefits through reduced requirement for N inputs, disease suppression, C sequestration, etc.

Estimates of FL-N fixation, measured using a laboratory based incubation (15N isotope) assay, ranged from <0.15 to 2.3 kg N fixed/ha/day under optimal soil moisture and temperature conditions. FL-N fixation ranged from 0.2 to 1.5 kg N/ha/day in sand and sandy loam soils in low to medium rainfall regions of southern and Western Australia compared to 0.5 to 2 kg/ha/day in the clay and loam soils in high rainfall regions. The number of optimal days per season does vary in different agricultural regions. The amount of N fixed varied with soil type and influenced by the time of sampling (in crop versus non-crop/fallow period), crop type and mineral nitrogen levels. The amount of FL-N fixed during summer significantly increases (>50%, $P < 0.05$) in the presence of summer-active grasses such as Rhodes grass and Panicum species, compared to winter-cereal crop only systems (Figure 7).

The abundance of FL-N fixing bacteria, percentage clay content (soil type), soil moisture content, and carbon availability are some of the major factors influencing FL-N fixation in cropping soils. Therefore, removal of stubble (one of the major sources of available C) either by burning or grazing would have negative impact on the amount of N fixed by FL-N_2 fixing bacteria. Research in the southern Australian agricultural region has shown that FL-N_2 fixation was higher immediately after harvest and decreased as summer progresses (Figure 7). Thus, careful consideration should be given to how stubble is managed in order to maximise FL-N fixation in cropping soils. Free-living N fixation is generally higher soon after rainfall when the water content is adequate to provide the required low-oxygen conditions (to protect O2-sensitive N fixing enzymes) and carry the carbon to where these bacteria are located. Higher levels of mineral N in the surface soil (0–10 cm) could have a negative effect on the amount of fixation by free-living bacteria, but this varies with soil type so needs region-specific solutions.

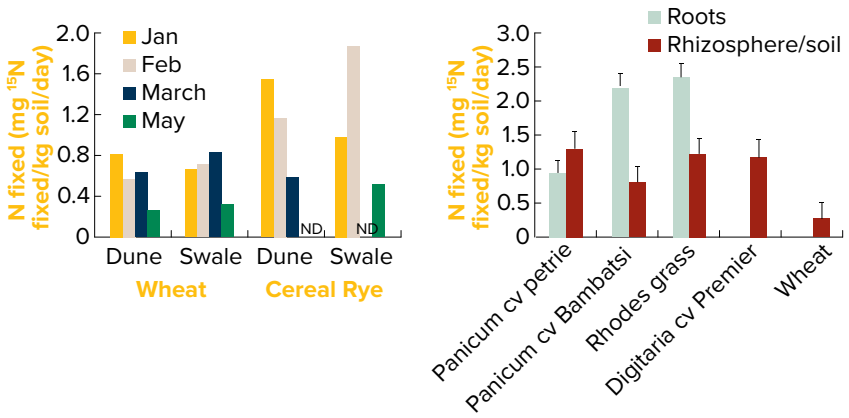

Figure 7: *Amount of free living (FL)-N fixation in soils collected from field experiment at Karoonda in SA during summer of 2011/12 (left) and with summer-active perennial grasses (right).*

Source: GRDC.

Soil type and stubble retention have a large influence on the abundance of nifH-gene harbouring bacteria, for example, abundance increased with clay content ($P < 0.01$) and stubble retention ($P < 0.05$). Populations of FL-N fixing bacteria are generally higher in the rhizosphere soil (soil closely surrounding roots) are generally higher than those found in the bulk soil.

Genetic profiling of N_2-fixing bacteria (nifH gene sequencing analysis) in cereal crop field soils (from SA, QLD, NSW, and WA) indicated the presence of a diverse group of free-living community (112 genera) in different agricultural regions indicating differences based on soil type and environment. Crop and variety types can influence the abundances of various groups thereby affecting the amount of FL-N fixation. Further research could suggest specific management strategies and identify crop varieties that help promote FL-N fixation by specific communities of N_2-fixing bacteria in different soils and regions.

Denitrification and gaseous N losses

The composition and abundance of soil bacteria involved in gaseous N losses (e.g. denitrification and nitrification) varies with soil type, and the denitrification losses are highest where soil nitrate N levels are high and when sufficient biologically available C is present along with low oxygen (O2) concentrations, e.g. water logging. In the southern Australian cropping regions, N losses are sporadic in time and space and vary widely in different agricultural systems. In cropping soils, the primary consideration for reducing gaseous N losses is by matching the supply of mineral N to crop demand and management practices that promote tie-up of N in microbial biomass (immobilisation) generally reduce N losses both through denitrification and leaching.

Nitrification of N fertilisers

The conversion of ammonia and urea N found in commonly used N fertilisers into nitrate N is a biological process mediated by specific group of microorganisms, e.g. nitrifiers, which are mostly abundant in the surface soils. The abundance and the type of nitrifiers present varies with soil type and depth and their activity can be influenced by management practices. Research has shown that banding fertilisers can influence the activity of these microbes and the accumulation of nitrate N. Thus, fertiliser N use efficiency could be manipulated by targeting fertiliser placement or the use of nitrification inhibitors. Immobilisation of fertiliser N in MB, becoming unavailable to plants, is generally short-term and has been found to be available to crops later in the crop season or to the following crop provided it is not leached or lost through gaseous losses.

Conclusions

- Nitrogen mineralised from soil organic matter (SOM) and crop residues makes a large contribution to crop N uptake (>50%).
- A diverse group of microbial communities are involved in the release of nitrate N from SOM and they are present in all agricultural soils.
- Management strategies (such as stubble retention, tillage, fertiliser application, and green manuring) and crop and variety selection can help manipulate microbial communities involved in N mineralisation from organic matter and crop residues and also influence fertiliser N use efficiency.
- Free-living N fixation can make an agronomically important contribution to the available N pool in stubble retained cereal based systems and perennial grass systems. [23]

23 Gupta V. 2016. GRDC Update papers – Factors influencing nitrogen supply from soils and stubbles. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Factors-influencing-nitrogen-supply-from-soils-and-stubbles

IN FOCUS

Factors regulating the contributions of fixed nitrogen by pasture and crop legumes to different farming systems of eastern Australia

On-farm and experimental measures of the proportion (%Ndfa) and amounts of N_2 fixed were undertaken for 158 pastures either based on annual legume species (annual medics, clovers or vetch), or lucerne (alfalfa), and 170 winter pulse crops (chickpeas, faba beans, field peas, lentils, lupins) over a 1200 km north-south transect of eastern Australia.

Although pulses often fixed more N than pastures, legume-dominant pastures provided greater net inputs of fixed N, since a much larger fraction of the total plant N was removed when pulses were harvested for grain than was estimated to be removed or lost from grazed pastures.

The net amounts of fixed N remaining after each year of either legume-based pasture or pulse crop were calculated to be sufficient to balance the N removed by at least one subsequent non-legume crop only when below-ground N components were included. This has important implications for the interpretation of the results of previous N_2 fixation studies undertaken in Australia and elsewhere in the world, which have either ignored or underestimated the N present in the nodulated root when evaluating the contributions of fixed N to rotations. [24]

MORE INFORMATION

Factors regulating the contributions of fixed Nitrogen by pasture and crop legumes to different farming systems of eastern Australia.

5.7.1 Deficiency symptoms

As proteins make up much of the content of cells, nitrogen is needed in greater quantity that any other mineral nutrient. Nitrogen plays an essential role in the production of chlorophyll, and any deficiency is displayed as yellowing leaves and reduced tillering in cereal crops. This ultimately leads to reduced yields.
Nitrogen is highly mobile within the growing plant, allowing it to re-mobilise and move to tissues that can use it more effectively. As a result, older leaves tend to exhibit nitrogen deficiency symptoms first.

Nitrogen fixation reaches the maximum level at flowering stage and then declines sharply during pod filling. Nitrogen deficiency restricts plant growth and reduce branching. Plants have fewer flowers. Fewer pods are formed resulting in poor yields.

What to look for

1. When nitrogen supply becomes restricted, the older leaves display deficiency symptoms first.
2. The entire plant appears chlorotic, while older leaves turn more yellow than upper leaves (Photo 2).
3. Pink pigmentation develops on the lower part of the stem (Photo 3 left).
4. In prolonged deficiency conditions, the lower leaves turn yellow with reddish-pink margins and a pink colouration develops on the lower stem (Photo 4).
5. In the later stage, the yellow older leaves turn white and drop prematurely (Photo 3 right). [25]

24 Peoples, M. B., Bowman, A. M., Gault, R. R., Herridge, D. F., McCallum, M. H., McCormick, K. M., ... & Schwenke, G. D. (2001). Factors regulating the contributions of fixed nitrogen by pasture and crop legumes to different farming systems of eastern Australia. Plant and Soil, 228(1), 29-41.

25 Kumar, P., & Sharma, M. K. (Eds.). (2013). Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

Photo 2: *Nitrogen-deficient crop in foreground compared with nitrogen-fertilised crop behind.*

Source: Kumar, P., & Sharma, M. K. (Eds.). (2013), Photo: Dr P. Kumar.

Photo 3: *Pink pigmentation on lower stem and pale yellow to white chlorotic older leaves (left). Severely deficient whiting yellow leaflets with reddish-pink colouration on the edges (right).*

Source: Kumar, P., & Sharma, M. K. (Eds.). (2013). Photo: Dr P. Kumar.

Photo 4: *Plant showing bottom leaves white, middle leaves yellow, and top leaves green.*

Source: Kumar, P., & Sharma, M. K. (Eds.). (2013). Photo: Dr P. Kumar.

5.7.2 Leaching

Once organic-N is converted to nitrate, it is prone to leaching, particularly in sandy textured soils in high rainfall zones where soil compaction problems slow root growth. Other subsoil constraints, such as soil acidity, may also reduce the efficiency of uptake of NO3- by the crop. Finer textured soils (e.g. red loams) are less likely to suffer significant NO3- to leaching, allowing efficient use of available nitrogen.

5.7.3 Managing Nitrogen

Cropping systems using carefully designed species mixtures may be a way to lower N fertilisation input, while maintaining economic profitability. [26]

Nitrogen fertilisers in small amounts (5–15 kg N/ha) are not harmful to nodulation and can promote early root growth to establish stronger plants. Fertiliser compounds such as MAP and DAP are suitable for chickpea production. Excessive amounts of nitrogen however, will restrict nodulation and reduce nitrogen fixation.

'Starter N' may be beneficial, but is not essential. [27]

Optimising nitrogen fixation in southern farming systems

Pulse and pasture legumes can provide an abundant, inexpensive, and sustainable source of nitrogen (N) for Australian cropping systems.

26 Hirel, B., Tétu, T., Lea, P. J., & Dubois, F. (2011). Improving nitrogen use efficiency in crops for sustainable agriculture. Sustainability, 3(9), 1452-1485.

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

Research at the South Australian Research and Development Institute (SARDI) is aiming to optimise N_2-fixation in southern farming systems by: improving our understanding of how cultivars differ in their N_2-fixation potential; clarifying where legumes respond to inoculation; identifying key agronomic factors affecting fixation; and testing new inoculants. The work has so far mainly focused on field peas.

Optimising agronomy

Agronomic practices such as time of sowing, crop nutrition, and managing disease and weed pressures—which optimise dry matter production of the pulse crop—also drive nitrogen demand and generally encourage N_2-fixation. Other factors can have more direct impacts on the symbiosis.

Mineral N at sowing

Pre-sowing mineral N in the soil (and also N applied in fertiliser at sowing) can impact on N_2-fixation. High levels of mineral N in the top 10 cm of soil at sowing (>30 kg/ha) may reduce the number of nodules which form per plant and will reduce N_2-fixation. When 30 kg of N was added at sowing, nodulation was reduced by 10 per cent and N_2-fixation by an average of 10 kg/ha.

Herbicides

Plant back times for herbicides should be strictly adhered to. Residues from sulfonylurea (SU) herbicides are known to retard root growth and development and the ability of roots to form nodules and then fix nitrogen. In-crop herbicides which cause significant yellowing and temporary stunting of crops also have the potential to reduce nitrogen fixation of the crop. These effects are thought to be more pronounced on light textured soils and when multiple stress factors are present (e.g. water, frost, SU residues).

Contributions of fixed N from legume roots are presently not well quantified and some work has begun to gain a better understanding of these contributions and how they might be managed. [28]

MORE INFORMATION

Soil Nitrogen supply factsheet.

5.8 Phosphorus

Key points

- Chickpeas are not as responsive to phosphorus fertiliser as some of the other pulses. In order to match the nutrient requirement of a crop yielding 1.5–3.5 t/ha, a guide for alkaline soils with a good fertiliser history is 7–16 kg/ha of phosphorus. This is equivalent to 80–186 kg/ha of single super or 40–95 kg/ha of double super. [29]
- Phosphorus cycling in soils is particularly complex, and agronomic advice is recommended when interpreting soil test results.
- Only 5–30% of phosphorus applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus does not move readily in soils, except very light sandy soils in high rainfall areas.

Ancient and highly weathered soils with very low levels of natural phosphorus (P) dominate much of Australia. Many of our agricultural soils are among the most acutely phosphorus-deficient in the world, and profitable crop production has only been possible through significant applications of P-fertilisers.
Phosphorus is an essential element for plant and animal growth and important during cell division and growth.
Complex soil process influence the availability of phosphorus applied to the soil, with many soils able to 'tie up' phosphorus, making it unavailable to plants. The

28 E. Farquharson, N. Charman and R. Ballard (SARDI). 2016. Optimising nitrogen fixation in southern farming systems. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Optimising-nitrogen-fixation-in-southern-farming-systems

29 Pulse Australia. Chickpeas in South Australia and Victoria. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpeas-SA-Vic.pdf

soil's ability to do this must be measured when determining requirements for crops and pastures. [30]

Soil phosphorus levels influence the rate of nodule growth. The higher the phosphorus level the greater the nodule growth. A 2 t/ha chickpea crop will on average remove approximately 6.5 kg/ha of phosphorus. This then is the minimum amount of phosphorus that needs to be replaced. Higher quantities may be needed to build up soil fertility or overcome soil fixation of phosphorus. [31]

Chickpeas are adapted to alkaline soils with high levels of unavailable P, and have evolved methods of extracting P, and some other nutrients, from the soil that would be inaccessible to many other pulse and cereal crops.

This ability is largely due to a combination of two factors: organic acids secreted from the root system and arbuscular mycorrhizalfungi (AMF) colonising the chickpea root system increasing uptake of P and Zn. More P may be required in low AMF situations (e.g. after a long fallow). High rates of (P) and Zinc will be required in most long fallow situations (fallows longer than 10 months) where soil VAM levels may be low. [32]

Based on information from the Northern region, chickpea is considered dependent on AMF to reach yield potential so yield reduction of 60–80% can occur in low AMF situations. [33]

High AMF situations

Where soil AMF levels are moderate–high (double-crop situations or short, six-month fallows from wheat), consistent responses to applied phosphate fertiliser are only likely where soil bicarbonate-P levels fall <6 mg/kg and are critically low.

Low AMF situations

Levels of AMF become depleted as fallow length is increased (Table 10), or after crops such as canola that do not host AMF growth. In these conditions of low AMF (long fallows of >8–12 months), chickpeas are very responsive to applied P and Zn. Although chickpeas in this situation will usually show a marked growth response to starter fertilisers (Table 11), this may not always translate into a positive yield response.

The most cost-effective strategy in a long fallow situation (low AMF) may be to ensure that the paddock is sown relatively early in the recommended sowing window, so that sufficient time is allowed for the crop to recover from the delay in early growth. These recommendations are based on soil samples taken to a depth of 0–10 cm.

Table 10: *An example of effect of fallow length on arbuscular mycorrhizae (AM) spore survival, and crop yield response to fertilisation after the fallow.*

Fallow duration (months)	AM Spores (no./g soil)	Crop yield (kg/ha)	
		Nil (P & Zn)	+ (P & Zn)
21	14	2865	4937
11	26	3625	3632
6	44	5162	4704

Source: J Thompson (1984).

Results in Table 11 show that chickpea growth on short-fallow land (six months after wheat) was much better than growth after long fallow on the same property. The addition of P and Zn fertilisers could not entirely compensate for the lack of AMF in chickpea on the long fallow.

30 Soilquality.org. Phosphorus – Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

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

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

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

MORE INFORMATION

VAM and long fallow disorder.

VIDEOS

3. CTV13: Phosphorus deficiency.

Table 11: *Effect of fallow length and fertiliser on chickpea growth (based on Northern region research).* [34]

Fallow duration (months)	Dry weight (g/plant) of chickpea at 12 weeks			
	Nil fertiliser	P (50 kg/ha)	Zn (10 kg/ha)	P & Zn
Long (14 months)	1	1.2	0.4	1.9
Short (six months after wheat)	3.1	2.8	2.7	3.3

One study found that there is a poor relationship between the commonly used indicator (Colwell P 0–10 cm) and the response to added P to chickpea. It has been suggested that a more reliable test than the Colwell P determination is warranted to get more efficient use out of applied P to inherently low P soils. [35]

5.8.1 Deficiency symptoms

Phosphorus deficiency is difficult to detect visually in many field crops, as the whole plant tends to be affected. Stunted growth, leaf distortion, chlorotic areas, and delayed maturity are all indicators of phosphorus deficiency. Phosphorus is concentrated at the growth tip, resulting in deficient areas visible first on lower parts of the plant.

A purple or reddish colour associated with accumulation of sugars is often seen in deficient plants, especially when temperatures are low. Deficient crops are often poorly tillered. Visual symptoms, other than stunted growth and reduced yield, are not as clear as are those for nitrogen and potassium. At some growth stages, phosphorus deficiency may cause the crop to look darker green.

The role of phosphorus in cell division and expansion means crop establishment and early growth is highly dependent on sufficient sources of the nutrient. Trials have shown significant agronomic penalties from applying phosphorus more than 10 days after germination. Most of these phosphorus timing trials indicate the optimum time for P-fertiliser application is before or during seeding. [36]

What to look for

1. Affected stems develop a reddish purple pigmentation that intensifies and becomes darker in prolonged deficiency conditions. (Photo 5).
2. In phosphorus-deficient plants, the top edges and upper surface of the leaflets exhibit reddish-purple discolouration (Photo 6). [37]

34 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

35 Routley, R., Spackman, G., & Conway, M. (2008). Variable response to phosphorous fertilisers in wheat and chickpea crops in central Queensland.

36 Soilquality.org. Phosphorus – Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

37 Kumar, P., & Sharma, M. K. (Eds.). (2013). Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

Photo 5: *Plant showing dark green leaves with reddish-purple discolouration in older leaves.*

Source: Kumar, P., & Sharma, M. K. (Eds.). (2013). Photo: Dr P. Kumar.

Photo 6: *Purpling appearing on edges of leaflets (left) through to purple pigmentation spreading inwards to cover upper srface of leaflets (right).*

Source: Kumar, P., & Sharma, M. K. (Eds.). (2013). Photo: Dr P. Kumar.

5.8.2 Do late sown crops need extra phosphorus?

As winter sowing dates get later, a crop's potential response to Phosphorus (P) fertiliser rises at the same time absolute yield potential is falling. This raises the question of what adjustments might need to be made to P fertiliser rates.

Plant physiology indicates that **later sown crops should be more responsive to P fertiliser**. Later sown winter crops usually grow more slowly. Their smaller root systems may reduce P uptake from the soil, compared to an early sown crop with a more developed root system, in contact with a greater volume of soil. **Actual**

trial results suggest response to higher rates of P fertiliser at late sowing is uncertain. [38]

5.8.3 Fate of applied fertiliser

Phosphorus fertiliser is mostly applied in a water soluble form which can be taken up by plants, retained by soil and lost through erosion and leaching (Figure 8). In the water soluble form phosphorus is not stable, and rapidly reacts in the soil (principally with iron, aluminium, and calcium) to form insoluble, more stable compounds. Therefore, competition between the soil and plant roots for water soluble phosphorus arises, with only 5% to 30% of the phosphorus applied taken up by the crop in the year following application. Furthermore, at low pH (<5.0), the soil's ability to fix phosphorus rises dramatically, thereby decreasing plant availability. [39]

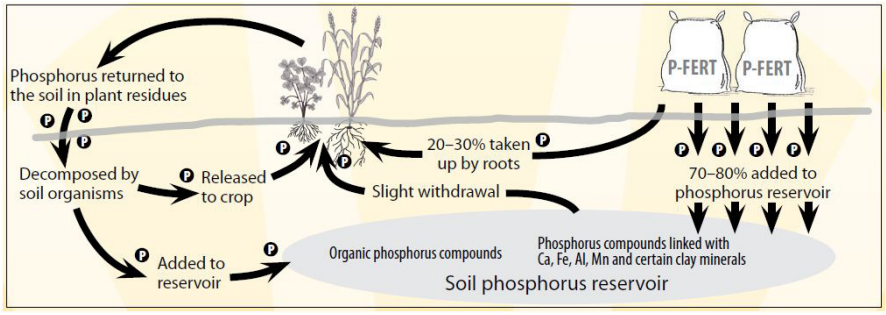

Figure 8: *The phosphorus cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited*

from Glendinning, 2000, in Soilquality.org.

5.8.4 Measuring a soil's ability to fix phosphorus

Knowing the soil's ability to fix phosphorus is vital in determining the rates of fertiliser application. A high-fixing soil will require significantly more P-fertiliser, and commercial tests have been developed to determine this. These are used in conjunction with other soil and crop traits to optimise fertiliser P requirements:

1. **Reactive Iron Test** measures the amount of iron extracted from soil by ammonium oxalate. This indirect measure of a soil's ability to fix P is only accurate when soil is adjusted for pH.
2. **Phosphorus Retention Index** (PRI) is a direct measure of P-sorption and involves mixing a quantity of soil in solution with a single amount of P for a set period of time. The amount of P remaining in solution measures the soil's ability to fix phosphorus.
3. **Phosphorus Buffering Index** (PBI) is similar to PRI except that a range of P rates are mixed with the soil, and the index is adjusted for pH. This is becoming the Australian standard for measuring soil P-sorption.
4. **Diffuse Gradient Technology Phosphorus** (DGT-P) is a relatively new method currently being tested for use with Australian soils, and mimics the action of the plant roots in accessing available phosphorus (see DGT-P factsheet). [40]

5.8.5 Phosphorus retention and removal

Phosphorus that is not removed from the soil system remains as (i) undissolved in fertiliser granules, (ii) adsorbed by the soil, or (iii) present in organic matter. These sources all supply some P for plant uptake and thus maintain a residual fertiliser value. A long term regime of applying P fertiliser decreases the capacity of the soil to

38 Conyers, M. 2016. Do late crops need extra phosphorus? http://extensionaus.com.au/crop-nutrition/do-late-sown-crops-need-extra-phosphorus/

39 Soilquality.org. Phosphorus – Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

40 Soilquality.org. Phosphorus – Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

adsorb phosphorus, giving increased effectiveness of subsequent applications. Each crop species will remove different amounts of phosphorus from soil following harvest (see Table 1), and must be accounted for during nutrient budgeting.

5.8.6 Leaching and placement of phosphorus

Phosphorus movement in soil varies depending on soil type, although it generally stays very close to where it is placed. With the exception of deep sandy soils, very little phosphorus is lost to leaching. Tests on loamy and clay soils with a history of P-fertiliser application show a rapid reduction in phosphorus with depth.
Agronomic benefits of banding P-fertiliser on high fixing soils have only been evident in trials with lupins, with this attributed to less soil coming in contact with the concentrated phosphorus layer. Wheat and canola have not responded to banded phosphorus on high fixing soils.
Placing high rates of phosphorus close to germinating seedlings can reduce germination and establishment, and should be placed at least 2 cm below the seed. Some considerations when banding phosphorus are:

- Drying conditions in the furrow following seeding, where a “salting” effect draws moisture from around the seed.
- Canola and lupins are more sensitive to higher phosphorus concentrations.
- Higher concentration of fertiliser in furrow when seeding at higher row spacing.
- Nitrogen-containing fertilisers (e.g. DAP) are more damaging than superphosphate fertilisers. [41]

5.8.7 Soil P testing

The Soil P test needs to be interpreted in association with the soil’s P-adsorption capacity, which is estimated by the PBI. The higher the PBI value, the more difficult it is for a plant to access P. Phosphorus is relatively immobile in soils and P applied to the 0 to 10 cm layer tends to remain in that layer, especially in no-till systems. This is the case for loams, duplexes, and red and yellow sands. However, grey sands have low P sorption capacity and P can leach from the 0 to 10 cm soil layer and accumulate in the layers below 10 cm. [42]

5.9 Sulfur

Sulfur (S) is needed at higher rates for chickpea. Sulfur is an important nutrient in the production of proteins and as such is used at a higher proportion than other non legume crops. On a relative yield basis S supply is similar for all crops, except canola which has a higher demand.

Use "grain legume" fertilisers. If the paddock has a history of single super and/or gypsum use, then S may be adequate, particularly on clay soils. Prolonged use of double or triple super could lead to an S deficiency, especially on lighter soils.

Historically, S has been adequate for crop growth because S was supplied in superphosphate. Sulfur deficiency occurs when growers repeatedly use high analysis N and P fertilisers that are low in S and in wet growing seasons due to leaching of S. Occurrence of S deficiency appears to be a complex interaction between the seasonal conditions, crop species, and plant availability of subsoil S. As with N, these factors impact on the ability of the soil S test to predict plant available S. [43]

Certain soil types are prone to S deficiency—for example, some basaltic, black earths. On these soils with marginal S levels, deficiency is most likely to occur with double-cropping where levels of available S have become depleted, for example.

41 Soilquality.org. Phosphorus – Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

42 GRDC. (2014). Crop Nutrition Fact Sheet – Western Region. Soil Testing for crop nutrition. www.grdc.com.au/GRDC-FS-SoilTestingW

43 GRDC. (2014). Crop Nutrition Fact Sheet – Western Region. Soil Testing for crop nutrition. www.grdc.com.au/GRDC-FS-SoilTestingW

5.9.1 Symptoms

- Sulfur deficiency symptoms are often seen in the early growth stage of the crop.
- Sulfur deficient plants become smaller and slender.
- The yield is severely reduced as the deficient plants produce fewer pods and smaller seeds.
- Deficiency symptoms of sulfur first appear and become more severe in younger leaves (Photo 7, left).
- Younger leaves turn pale green to pale yellow, while the lower leaves remain dark green.
- In severe deficiency conditions, the youngest leaflets turn completely yellow (Photo 7, right) and the entire plant can turn chlorotic. [44]

Photo 7: *Yellowing intensified on younger leaflets (left). Leaflets showing uniform yellowing (right).*

Source: Kumar, P., & Sharma, M. K. (Eds.). (2013). Photo: Dr P. Kumar.

5.9.2 Applying sulfur

Application of 5–10 kg S/ha will normally correct S deficiency. Where soil phosphate levels are adequate, low rates of gypsum are the most cost-effective, long-term method of correcting S deficiency.

Granulated sulfate of ammonia is another effective option where low rates of N are also required.

Marked responses to 25 kg/ha of sulfate of ammonia have been observed when sowing chickpeas in double-crop situations. [45]

IN FOCUS

Growth, nitrogen fixation and nutrient uptake by chickpea (*Cicer arietinum*) in response to phosphorus and sulfur application under rainfed conditions in Pakistan.

A field experiment was conducted to assess the seed yield, nitrogen fixation and nutrient uptake by chickpea (Cicer arietinum L.) in response to application of different levels of phosphorus (P) and sulfur (S). The treatments comprised three levels (0, 40, and 80 kg P 2O 5 ha -1) of P and three levels (0, 15, and 30 kg S ha -1) of S from two sulfur sources (gypsum & ammonium sulfate) in different combinations. In a soil with 3 ppm of phosphorus and 6 ppm of sulfur, application of P and S resulted in significant yield increases under rainfed conditions. The addition of sulfur had a direct effect on N fixation and also resulted in the improvement of

44 Kumar, P., & Sharma, M. K. (Eds.). (2013). Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

45 Pulse Australia (2013) Northern chickpea best management practices training course manual http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide Limited.

protein content. Application of P and S resulted in significant increase in seed yield by 21% and 12% more than control, respectively. Sulfur application had significant effect on percent nitrogen derived from atmosphere (% N dfa), while effect of P was non-significant. There was significant increase in protein content of chickpea seed due to application of S. Application of both P and S resulted in increase in nitrogen (N) fixation by 16%. An economic analysis indicated that the most profitable application of P and S on this soil was 40 kg/ha P and 30 kg/ha S. [46]

5.10 Potassium

Diagnosis of potassium (K) deficiency before visual symptoms occur is important in order to avoid large yield losses. K is mobile and readily transferred from old to young leaves when a deficiency occurs.

Factors such as soil acidity, soil compaction, and waterlogging will modify root growth and the ability of crops to extract subsoil K. Consequently, interrogation of results across all soil types has identified a poor relationship between the soil test for K and crop yield response.

However, the critical value (0 to 10 cm) for K is defined across all soil types as 41 mg K/kg to achieve a relative yield of 90% (for wheat). [47]

IN FOCUS

Diagnosis of potassium deficiency in faba bean and chickpea by plant analysis

Critical potassium (K) concentrations for the diagnosis of K deficiency were determined in various shoot parts of faba beans (Vicia faba L.cv. Fiord) and chickpeas (Cicer arietinum L. T1587) plants grown at K rates of 0–240 mg K/kg in a K-deficient soil in the glasshouse. It is recommended that the critical values for the diagnosis of K deficiency at 7–8-leaf stages are 1.3–1.5% in the youngest fully extended leaf (YFEL), 1.1–1.2% in the 1st plus 2nd leaf blades below the YFEL and 1.8–2.0% in whole shoot of faba bean, and 1.4–1.5% in YFEL, 2.7–2.8% in the 1st plus 2nd leaf petioles, and 2.1–2.2% in whole shoot of chickpea. [48]

46 Islam, M., Mohsan, S., Ali, S., Khalid, R., UL-HASSAN, F. A. Y. Y. A. Z., Mahmood, A., & Subhani, A. (2011). Growth, Nitrogen Fixation and Nutrient Uptake by Chickpea (*Cicer arietinum*) in Response to Phosphorus and Sulfur Application under Rainfed Conditions in Pakistan. International Journal of Agriculture & Biology, 13(5).

47 GRDC. (2014). Crop Nutrition Fact Sheet – Western Region. Soil Testing for crop nutrition. www.grdc.com.au/GRDC-FS-SoilTestingW

48 Aini, N., & Tang, C. (1998). Diagnosis of potassium deficiency in faba bean and chickpea by plant analysis. Animal Production Science, 38(5), 503-509.

5.10.1 Symptoms

Photo 8: *Tips of leaflets show brown necrotic patches and eventually die.*

Photos: Michael Bell, QAAFI.

Photo 9: *Margins and tips of lower leaves show chlorosis.*

Photos: Michael Bell, QAAFI.

5.10.2 Applying potassium

Responses to K are unlikely on most black earths and grey clays. Potassium fertilisers may be warranted on red earths (kraznozems) but this should be based on soil analysis. Fertiliser responses are likely where soil test levels using the ammonium acetate test fall below:

- exchangeable K of 0.25 meq/100 g (or cmol/kg) on black earths and grey clays
- exchangeable K of 0.40 meq/100 g K on red earths and sandy soils.

Application of 20–40 kg K/ha banded 5 cm to the side of, and below, the seed line is recommended in situations where soil test levels are critically low. Alternatively, blends such as Crop King 55 (13 N,13 P,13 K) may be considered at rates of 80–120 kg/ha in situations where K levels are marginal. [49]

5.11 Micronutrients

Why is there a need for micronutrients/trace elements?

Essential trace elements are nutrients which are required by plants and animals to survive, grow, and reproduce but are needed in only minute amounts. Southern cropping soils are more likely to be deficient in zinc (Zn), copper (Cu), and manganese (Mn) than the other trace elements.

Of these three, Zn deficiency is probably the most important because it occurs over the widest area. Zn deficiency can severely limit annual pasture legume production and reduce cereal grain yields by up to 30 per cent.

Cu deficiency is also important in pollen viability, carbohydrate and protein synthesis, photosynthesis, cell wall stability and other metabolic functions. Deficiency occurs in limited soils, and needs to be monitored by soil and plant tests, local knowledge of responses, and in field trials/strips. Cu deficiency can cause significant losses.

If these three trace elements are not managed well the productivity of crops and pastures can suffer economic losses, and further production can also be lost through secondary effects such as increased disease damage and susceptibility to frost.

Adequate trace element nutrition is just as important for vigorous and profitable crops and pastures as adequate major element (such as nitrogen or phosphorus) nutrition. [50]

Molybdenum and cobalt are required for effective nodulation and should be applied as needed. Foliar sprays of zinc and manganese are a useful method of treating deficiency on high pH soils where soil fixation of these nutrients occur. [51]

5.11.1 Zinc

Zinc occurs in low levels in all Australian soils and is known to be deficient in many of the areas that chickpeas are grown, including the sandy and calcareous soils of Northern Vic and SA. As an important nutrient to all crop growth and understanding of zinc nutrition is vital to the successful chickpea production.

Soils low in available zinc (Zn) occur in many areas of the world where chickpea is grown. Improving the ability to grow and produce high yield under limited supplies of Zn (often referred to as Zn efficiency) may increase productivity of chickpea in many of these regions.

Chickpea is considered to have a relatively high demand for zinc, but also possess highly efficient mechanisms for extracting Zn from the soil. Zinc seed treatments may be a cost-effective option in situations where soil P levels are adequate but zinc levels are likely to be deficient.

Chickpeas are prone to zinc (Zn) deficiency. Low or marginal zinc levels are widespread in many cropping districts. Zinc, and to a lesser extent iron, deficiency is prevalent on calcareous soils, particularly dark brown clay soils with high pH.

Zinc applications lasts about two years on calcareous clays and 6–7 years on loamy soils. Zinc is not mobile in the soil and an even distribution is important. Zinc

49 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

50 GRDC Update Papers. 2016. 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

51 Matthew Witney (2016). Personal Communication.

can be applied by spray to the soil, in furrow, coated on granular fertiliser or as a foliar spray. [52]

Zinc deficiency affects plant-water relationships, induces stomatal closure and decreases transpiration in plants.

IN FOCUS

Response of chickpea genotypes to zinc fertilisation under field conditions in South Australia

The effects of Zn on the growth, grain yield and tissue ZN concentration of a number of chickpea genotypes were compared in one field experiment in South Australia. The DPTA-extractable Zn at the sites ranged from 0.24 to 0.30 mg kg−1. In each experiment 10 genotypes were grown with or without additional Zn. Except for Tyson, the genotypes differed between the two experiments in South Australia. Grain yield responses to applied Zn ranging from 7% to 19%, occurred at each site. The rankings for Zn efficiency from the field experiments were significantly correlated with the rankings in previous pot trials. The high levels of zinc efficiency suggested that significant genetic gains in productivity under conditions of low Zn supply are possible. The ability of pot trials to predict performance under field conditions indicates that screening for zinc efficiency can be successfully conducted in the glasshouse. [53]

Symptoms

It is very difficult to diagnose Zn deficiency in pasture or grain legumes because the characteristic Zn deficient leaf markings are rarely produced in the field. Zn deficiency causes shortening of stems and the leaves fail to expand fully. This results in plants which appear healthy but are stunted and have small leaves. Plant symptoms appear to be worst early in the season when conditions are cold and wet and light intensity is low. In spring, symptoms often do not appear on new leaves but grain yields will usually be reduced.

- Zinc deficient plants appear stunted and have fewer branches. The size of leaflets is reduced. Crop maturity gets delayed.
- The younger leaves become pale green first, then a reddish-brown discolouration appears on margins of leaflets and on the lower parts of the stem (Photo 10, left).
- In severe deficiency, bronzing and necrosis occurs on the leaflets (Photo 10, right). [54]

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

53 Khan, H. R., McDonald, G. K., & Rengel, Z. (2000). Response of chickpea genotypes to zinc fertilisation under field conditions in South Australia and Pakistan. Journal of plant nutrition, 23(10), 1517-1531.

54 Kumar, P., & Sharma, M. K. (Eds.). (2013). Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

Photo 10: *Reddish-brown pigmentation spreading on the entire upper surface of the leaflets (left). Deficient leaflets showing reddish pigmentation and necrosis on the margins (right).*

Source: Kumar, P., & Sharma, M. K. (Eds.). (2013). Photo: Dr P. Kumar.

Correcting Zinc deficiency in southern Australia

Correction of Zn deficiency in a way which provides benefits after the year of treatment is possible through the use of Zn-enriched fertilisers or a pre-sowing spray of Zn onto the soil (incorporated with subsequent cultivations).

Another option that will also provide long term benefits but has become available only recently is the application of fluid zinc at seeding. The advantage of this approach is that it will provide residual benefits for subsequent crops and pastures and has a low up-front application cost (providing you ignore the capital investment in a fluid delivery system!). At current prices, a typical application may cost about $6.00/ha (this is 1 kg of Zn/ha).

Only Zn-enriched fertilisers of the homogenous type (fertiliser manufactured so that all granules contain some Zn) are effective at correcting Zn deficiency in the first year of application. A rate of two kilograms of elemental Zn per hectare applied to the soil is necessary to overcome a severe Zn deficiency and should persist for three to ten years (depending on soil type). Short intervals between repeat applications of Zn will be necessary on heavy and calcareous soils in the high rainfall areas, while seven to ten year intervals will be acceptable in the low rainfall areas. Following an initial soil application of 2 kg Zn/ha repeat applications of 1 kg/ha will probably be sufficient to avoid the reappearance of Zn deficiency in crops and pastures. Most zinc-enriched fertilisers are now not sold as pure homogeneous types, but providing a homogeneous fertiliser is used as part of the mix then the final product is still satisfactory for correcting Zn deficiency. For example, the company may produce a diammonium phosphate (DAP) Zn five per cent 'parent' product which has Zn on every granule which they will then blend with straight DAP to give 1 and 2.5 per cent products for the retail market.

Zn deficiency can be corrected in the year that it is recognised with a foliar spray of 250–350 g Zn/ha but it has no residual benefits and is therefore not the best approach for a long-term solution. Zinc can be mixed with many herbicides and pesticides but not all, so check with your supplier for compatible tank mixes before you make the brew. Recent trials in eastern Australia suggest that chelated sources of trace elements are no more effective at correcting a deficiency than sulfates (see Photo 1 for an example of treating copper deficiency in wheat), although older results from WA showed that there are situations where they can be superior.

Seed dressings of zinc are another option for managing Zn deficiency. These products are effective and will supply Zn to the young crop but they will not completely overcome a severe deficiency. Nor will they increase soil reserves of Zn. Seed with high internal levels of Zn can also be used in a similar way. However, both approaches should be used in conjunction with soil applications to correct and manage Zn deficiency in the long term. This option will currently cost approximately $3.00/ha. [55]

Applying Zinc

There is a lack of Australian and overseas research on Zn responses in chickpeas, and Zn fertiliser recommendations are being conservatively based on a general recommendation used for all crops. Based on DTPA analysis of soil samples at 0–10 cm, critical values of Zn are:

- below 0.8 mg/kg on alkaline soils
- below 0.3 mg/kg on acid soils.

In the Northern region, AMF are important to Zn nutrition in chickpeas, and large responses can be expected where AMF levels have become depleted due to long fallows (over 8–10 months). This is not so much of an issue in the Southern region.

Pre-plant treatments

Severe Zn deficiency can be corrected for a period of 5–8 years with a soil application of 15–20 kg/ha of zinc sulfate monohydrate, worked into the soil 3–4 months before sowing.

Zinc is not mobile in the soil and needs to be evenly distributed over the soil surface, and then thoroughly cultivated into the topsoil. In the first year after application, the soil-applied Zn may be not fully effective and a foliar Zn spray may be required.

Fertilisers applied at sowing

A range of phosphate-based fertilisers either contain, or can be blended with, a Zn additive.

Foliar zinc sprays

A rate of two kilograms of elemental Zn per hectare applied to the soil is necessary to overcome a severe Zn deficiency and should persist for three to ten years (depending on soil type). Short intervals between repeat applications of Zn will be necessary on heavy and calcareous soils in the high rainfall areas, while seven to ten year intervals will be acceptable in the low rainfall areas. Following an initial soil application of 2 kg Zn/ha repeat applications of 1 kg/ha will probably be sufficient to avoid the reappearance of Zn deficiency in crops and pastures. [56]

A foliar spray per ha of 1.0 kg zinc sulfate heptahydrate + 1.0 kg urea + 1200 mL of non-ionic wetter (1000 g/L) in at least 100 L of water will correct a mild deficiency. One or two sprays will need to be applied within 6–8 weeks of emergence.

Hard water (high in carbonate) will produce an insoluble sediment (zinc carbonate) when the zinc sulfate is dissolved, with the spray mix turning cloudy. Buffer back with L1-700 or Agri Buffa if only hard water is available; zinc oxide products are highly alkaline, with a pH of 9.5–10.5. [57]

55 GRDC Update Papers. 2016. 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

56 GRDC Update Papers. 2016. 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

57 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited

IN FOCUS

Chickpea response to zinc, boron and molybdenum application under Mediterranean field conditions

In some growing regions, Chickpea is cultivated on non-irrigated soils with low native fertility. This study was carried out from 2006 to 2008 in Spain, under acid soil field conditions, with the aim of determining whether the application of zinc (Zn), boron (B) and molybdenum (Mo) improved chickpea growth and yield on acid soils. A split-split-plot design with three replications was used. Chickpea responded only to the Zn and Mo applications. At maturity, plants fertilised with Zn and with Mo had a greater total dry matter production and seed yield, mainly due to an increment in pod dry matter. For Zn, the highest yield was obtained with 2 mg Zn per plant (6.80 g plant−1), whereas for Mo the highest yield was obtained with 1 mg Mo per plant (6.73 g plant−1). Interaction was observed between B and Mo, interpreted as indicating that Mo can counteract the effect of B application. [58]

5.11.2 Boron

Key points

- Boron is essential for plant growth, but only needed in very small amounts.
- Soils deficient in boron are often deep sands in high rainfall zones.
- Toxic levels of boron tend to be found in the heavier soils of the Mallee regions.
- Boron toxicity is best managed through the use of crops that exhibit tolerance to the nutrient.

Boron (B) is essential for crop growth and development but in very small quantities. While the precise role of boron in plants is not fully known there is evidence to show that boron is important for cell division, the production of nucleic acids (DNA, RNA), the movement of sugars across membranes and the development of reproductive structures (i.e. pollen tubes, fruit, grain). [59]

For most crops, 1–4 mg-B/kg soil is sufficient to prevent nutrient deficiencies. Less than 0.5 mg-B/kg is rated as marginal to deficient. Boron is generally present in soils as B4O72-, H2BO3-, HBO32-, and BO33-. Each of these ionic forms are readily leached under high rainfall conditions. Acid deep sands in higher rainfall regions (>600 mm) where there is little clay and organic matter within the root zone are at most risk of having low boron levels. Symptoms of boron deficiency vary between plants ranging from hollow cavities in vegetable crops, distorted growing tips, discoloration and a ‘corky’ appearance in fruit and flower and pod abortion in canola. Symptoms are most noticeable in actively growing sites.

Boron toxicity

Soil pH affects the availability of most nutrients. Occasionally, some nutrients are made so available that they inhibit plant growth. For example on some acid soils, Al and Mn levels may restrict plant growth, usually by restricting the rhizobia and so the plant’s ability to nodulate.

58 Valenciano, J. B., Boto, J. A., & Marcelo, V. (2011). Chickpea (*Cicer arietinum* L.) response to zinc, boron and molybdenum application under field conditions. New Zealand Journal of Crop and Horticultural Science, 39(4), 217-229.

59 Soil Quality.org. Boron – Western Australia. http://www.soilquality.org.au/factsheets/boron

Boron toxicity in Australia is mainly confined to the low rainfall (<550 mm/yr) Mallee vegetation communities of, South Australia, Victoria, and Western Australia. The soils typically contain highly alkaline (pH >8) and sodic clay subsoils which are poorly leached and have boron concentrations >12 mg-B/kg of soil. Often boron toxic soils have formed from marine sediments or boron rich minerals including tourmaline.

Chickpeas are considered sensitive to boron toxicity and occurs on many of the alkaline soils of the southern cropping areas. Symptoms show as a yellowing or dying of the tips and margins of the leaves, with the older leaves being more severely affected than younger leaves (Photo 11). There appears to be little difference in reaction between current varieties. [60]

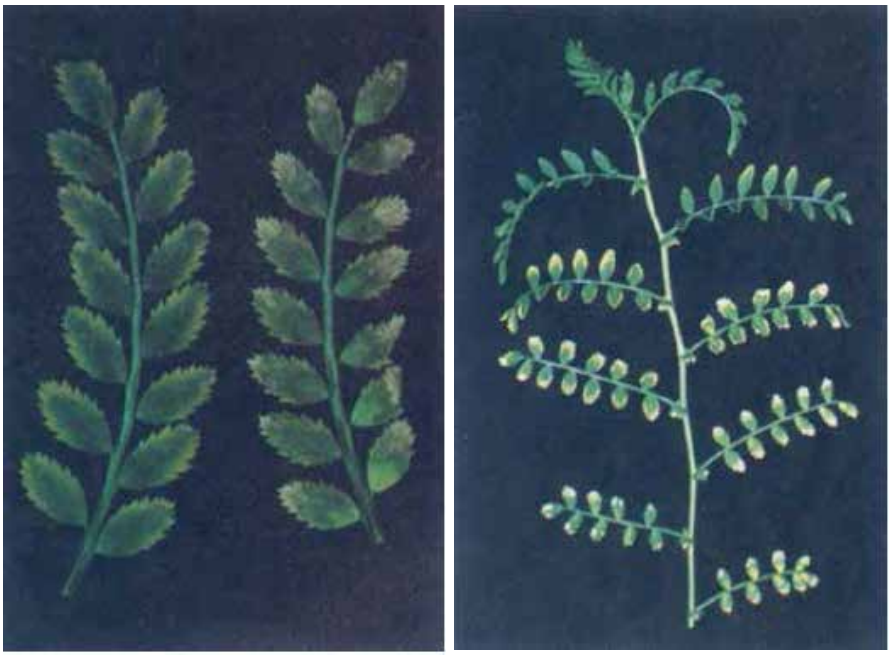

Photo 11: *Symptoms of boron toxicity in chickpea leaves.*

Source: CSIRO.

Managing boron toxicity can be achieved through leaching, the application of amendments and using tolerant varieties. Irrigating to encourage leaching is highly effective. However, in the absence of irrigation water, amending soils with gypsum can increase water infiltration in sodic clays and consequently leach boron deeper into the soil. Dryland trials have shown high rates of gypsum over 20 years can leach boron approximately 10–20 cm. In some circumstances, foliar sprays of zinc have been shown to alleviate boron toxicity, although the interaction between boron and zinc is poorly defined.

Boron testing

Soil testing is considered the best method for determining the presence of boron deficiency or toxicity. However due to the high spatial variability in soil boron, testing needs to be done strategically in areas of high and low plant production and throughout the root zone. Due to the mobile characteristics of boron in soil, the most accurate determination of boron status is to sample soil to depth. Hot water extraction in 0.01 M $CaCl_2$ solution is the recommended method for determining soil boron. Plant tissue testing is less reliable as critical limits cannot be easily determined due to the uneven accumulation of boron in plant tissues, variation in boron uptake at different growth stages and the leaching of boron from plant tissue during rainfall. Seed testing is seen as a more reliable method for determining potential boron

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

toxicity. Grain with more than 3 mg-B/kg is likely to have been grown in boron toxic soils. [61]

5.11.3 Iron

Chickpeas vary in their sensitivity to iron (Fe) deficiency. Considerable yield losses due to iron deficiency chlorosis may occur when susceptible varieties are grown in calcareous soils with high pH. Iron deficiency generally results in stunted growth, with deficient plants showing poor nodulation. [62]

Major problems with Fe deficiency have largely been overcome through plant breeding. Iron deficiency symptoms tend to be transient, with the crop making a rapid recovery once the soil begins to dry out following a waterlogging event.

Iron deficiency is observed occasionally on alkaline, high-pH soils. It is usually associated with a waterlogging event following irrigation or heavy rainfall, and is attributed to interference with iron absorption and translocation to the foliage.

A mixture of 1 kg/ha of iron sulfate + 2.5 kg/ha of crystalline sulfate of ammonia (not prilled) + 200 mL of non-ionic wetter added to 100 L water has been successfully used to correct Fe deficiency.

The addition of sulfate of ammonia will improve absorption of Fe, with a significantly better overall response. [63]

Symptoms

- Plants display deficiency symptoms first on younger leaves which turn bright yellow then white, while older leaves remain dark green (Photo 12).
- As symptoms advance, white necrotic areas develop in the distal half of the leaflets in young leaves.
- In the later stage of deficiency, the white necrotic areas enlarge and the leaves wither, die and drop off. [64]

Photo 12: *Leaflets of younger leaves are uniformly bright yellow to white, while older leaves remain dark and healthy.*

Source: Kumar, P., & Sharma, M. K. (Eds.). (2013). Photo: Dr P. Kumar.

5.12 Nutritional deficiencies

Many soils in the cropping zone of southern Australia are deficient in trace elements in their native condition. Despite many decades of research into trace element management, crops can still be found to be deficient in one or more of these trace elements. Just because trace element deficiencies have not been prevalent in recent years, does not mean they will not return.

61 Soil Quality.org. Boron – Western Australia. http://www.soilquality.org.au/factsheets/boron

62 Kumar, P., & Sharma, M. K. (Eds.). (2013). Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

63 Pulse Australia (2013) Northern chickpea best management practices training course manual http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide Limited.

64 Kumar, P., & Sharma, M. K. (Eds.). (2013). Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

There is increasing concern in some districts that trace element deficiencies may be the next nutritional barrier to improving productivity. This is because current cropping systems are exporting more nutrients to the grain terminal than ever before.

Making use of the crop nutrition information available to you

As part of the Grains Research and Development Corporation (GRDC) More Profit from Crop Nutrition (MPCN) extension and training for the southern region project (BWD00021), BCG, in conjunction with other grower groups has been hosting nutrition events across the southern region since 2012.

Many key nutrition areas are being investigated through the MPCN initiative; however, there are a few immediate resources available to advisers to help with understanding nutrition and giving such advice.

Useful resources:

- eXtension Aus—Crop Nutrition: Connecting the lab and the paddock in crop nutrition. Providing updates on the latest research, and articles focusing on strategic management of crop nutrition in the current season. @AuCropNutrition
- BFDC—Better Fertiliser Decisions for Cropping: Fertiliser decisions made by grain growers should all start with, and rely on, knowledge of the fertility status of paddocks. These decisions need to account for the nutrient requirements of plants for growth, nutrient availability in soils, and nutrient losses that can occur during crop growth (e.g. de-nitrification or erosion).
- The Making Better Fertiliser Decisions for Cropping Systems in Australia (BFDC) provides the fertiliser industry, agency staff and agribusiness advisors with knowledge and resources to improve nutrient recommendations for optimising crop production. BFDC is recognised by the Fertiliser Industry Federation of Australia as the best available data for supporting the decision tools that fertiliser industry members use to formulate recommendations.
- MPCN—Extension and training for the Southern region. [65]

65 GRDC Update Papers. 2016. Making use of the crop nutrition information available to you. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Making-use-of-the-crop-nutrition-information-available-to-you