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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 | GREEN AND BROWN MANURING

Nutrition and fertiliser

Key messages

- Incorrect levels of nutrients (too little, too much or the wrong proportion) can cause plant growth problems.
- The main method to maintain or restore soil nutrients and help increase crop yields is applying mineral fertilisers such as nitrogen (N).
- A soil or plant tissue test will help to identify what nutrients are missing or in excess.
- Become familiar with plant and paddock symptoms of various nutritional deficiencies.
- If chickpea plants have effectively nodulated, they should not normally need N fertiliser.
- Molybdenum (Mo) and cobalt (Co) 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 in high-pH soil types.

Incorrect levels of nutrients (too little, too much or the wrong proportion) can cause plant growth problems. If the condition is extreme, plants will show visible symptoms that can sometimes be identified. Visual diagnostic symptoms are readily obtained, and 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]

The main method to maintain or restore soil nutrients and help increase crop yields is applying mineral fertilisers such as nitrogen (N) and phosphorus (P). [3]

The more attention we pay to all of the activities that contribute to nutrient management (Figure 1), the better the outcome we will get from soil and plant testing. Testing may not provide a useful contribution if one or more of these steps is not done well.

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

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

3 B Hirel, T Tétu, PJ Lea, F Dubois (2011) Improving nitrogen use efficiency in crops for sustainable agriculture. Sustainability, 3(9), 1,452–1,485.

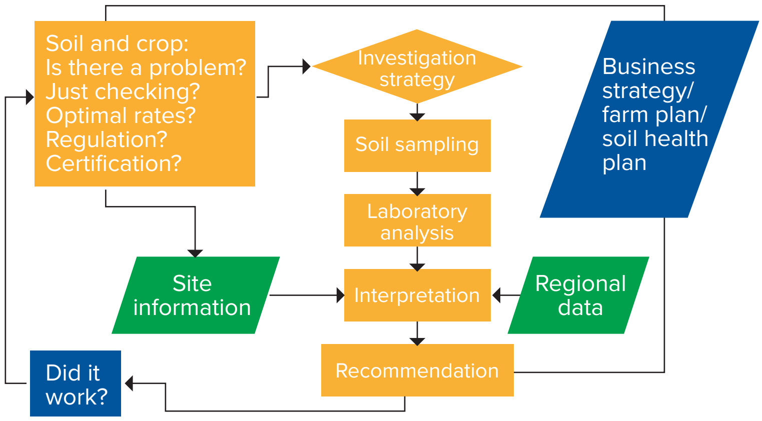


Figure 1: *Nutrient management flow chart.* [4]

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 nitrogen (N), phosphorus (P) and potassium (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. It should be noted 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 useful. 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 molybdenum (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 (waterlogging) 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 increase and may restrict plant growth, usually by restricting the rhizobia and consequently 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. [5]

4 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

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

Effect of macro and micronutrients on grain yield in chickpea crops

Key findings:

- If any single nutrient is lacking or not adequately balanced with other nutrients, crop growth may be suppressed or inhibited.
- The application of macro and micronutrients to a crop that was both moisture and temperature stressed led to a reduction in yield. [6]

5.2 Crop removal rates

If the nutrients (P, N, Zn, etc.) removed as grain from the paddock are not replaced, crop yields and soil fertility may fall. This means that fertiliser inputs must be matched to expected yields and soil type. Often, 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. From the table, a 2 t/ha crop of chickpeas will on average remove ~ 6.5 kg/ha of P. This amount of P will need to be replaced, unless soils are already high in P. 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 that, on soil tests have <50 µ g/g (ppm) (bicarbonate test) of K, may 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. [7]

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.

6 A Verrell & L Jenkins, GRDC (2015) Effect of macro and micro nutrients on grain yield in chickpea crops https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Effect-of-macro-and-micro-nutrients-on-grain-yield-in-chickpea-crops-at-Trangie-and-Coonamble

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

Table 2: *An example of nutrient budgeting.* [8]

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 the simple nutrient budget in Table 2, some interpretation 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 that 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 to at least replace the K used by the crop. However, soils high in K may not need replacement in the short term.
- 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.

8 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 towards 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. [9]

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, Mo is required by pulses to complete the process of N fixation. [10]

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 the plant requires. 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 whether at a certain soil concentration 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).

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

10 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.
- A single database collated more than 1,892 trials from Western Australia for different crops.
- Nutrient sufficiency is indicated if the test value is above the critical range.
- Where the soil test falls below the critical range there is likely to be a crop yield response from added nutrients.
- Critical soil test ranges have been established for 0–10 cm and 0–30 cm of soil.
- 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. [11]

In Western Australia, profitable grain production depends on applied fertiliser, particularly N, P, K S. 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, the previous year's nutrient removal and soil type, soil tests can help in making fertiliser decisions.

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.

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

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

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

5.4.1 Types of test

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

- bicarbonate extractable P (Colwell-P);
- bicarbonate extractable K (Colwell-K);
- KCl-40 extractable S; and
- 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.

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

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 in WA (see Tables 3 and 4). Soil sampling depth for nutrient analysis is currently 0–10 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 been long understood. To obtain more comprehensive soil data, including nutrient data, sampling to 30 cm should be considered, providing there are no subsoil constraints (Figure 2). 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.

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.

Figure 2: *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

Critical values and ranges

A soil test critical value is the soil test value required to achieve 90% 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.*

Nutrient	Crop	Soil types	Critical values (mg/kg)	Critical range (mg/kg)
P	Wheat	Grey sands	14	13–16
		Other soils	23	22–24
	Lupins	Grey sands in Northern Region	9	6–12
		Yellow sands in Northern Region	22	21–23
		Grey sands in Southern Region	12	10–15
		Yellow sands in Southern Region	30	25–37
	Canola	All	19	17–25
K	Wheat	All	41	39–45
		Yellow sands	44	34–57
		Loams	49	45–52
		Duplexes	41	37–44
	Lupins	Grey sands	25	22–28
	Canola	All	44	42–45
S	Wheat	All	4.5	3.5–5.9
	Lupins	All	n/a	N/A
	Canola	All	6.8	6.0–7.7

Source: DAFWA and Murdoch University in 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 (see 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. http://www.grdc.com.au/GRDC-FS-SoilTestingW

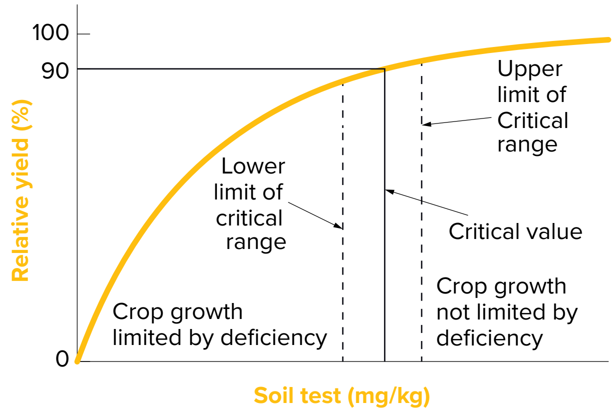


Figure 3: *Generalised soil test response calculation curve. A generalised soil test/crop response relationship defining the relationship between soil test value and percent grain yield expected. A critical value and critical range are defined from this relationship. The relative yield is the unfertilised 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: DAFWA, Murdoch University in GRDC

MORE INFORMATION

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

5.4.2 West Australian Soil Quality Monitoring Program

Key Points

- Soil quality is currently being measured in grain producing areas across Australia.
- The Soil Quality Monitoring Program and associated website (www.soilquality.org.au) provides 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.

The Soil Quality website provides an, interactive resource to the Australian grains industry on soil quality, including soil biology, soil chemistry and physics. The website allows growers to benchmark their paddocks against values for their local catchment and region, as well as against expert opinion. This information aids growers in determining 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 website are expanding to include grain producing areas across Australia. This will give growers access to regionally specific data on soil biological, chemical and physical constraints to production. This will in turn aid the Australian grains industry in making 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 The National Soil Quality Monitoring Program. http://www.soilquality.org.au/factsheets/w-a-soil-quality-program

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 87 lists the plant analysis criteria for chickpea. 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 (see Table 8, above) 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. [14]

5.6 Fertiliser

Fertiliser recommendations for chickpeas—as with most pulses—tend to be generic, with an overreliance on the recommendation of MAP-based starter fertilisers across nearly all situations. This is often driven by convenience and availability rather than to meet 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; and
- effectiveness of inoculation techniques.

Molybdenum (Mo) 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 the nodule growth.

Nitrogen (N) 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

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

sown down the same tube. The acidity of some fertilisers will kill large numbers or rhizobia. Neutralized 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 [15]

WATCH: Western communicator video: Gray Robertson.

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 causes 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 can be high.

The effects of toxicity 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.

Deep banding of fertiliser is often preferred for chickpeas, 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. [16]

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

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

Topdressing P on heavy soils can be relatively ineffective.

Agronomist's view

5.7 Nitrogen

Key points:

- Nitrogen (N) is needed for crop growth in larger quantities than any other nutrient.
- Nitrate (NO3-) is the highly mobile form of inorganic nitrogen in both the soil and the plant.
- Sandy soils in high rainfall areas are most susceptible to nitrate loss through leaching.
- Soil testing will help determine seasonal nutrient requirements. [17]

Plants require more nitrogen (N) than any other nutrient, but only a small portion of the N in soil is available to plants—98% of the N in soil is in organic forms. Most forms of organic nitrogen cannot be taken up by plants, with the exception of some small organic molecules. In contrast, plants can readily take up mineral forms of N, including nitrate and ammonia. However, mineral nitrogen in soil accounts for only 2% of the N in soil. Soil microorganisms convert organic forms of nitrogen to mineral forms when they decompose organic matter and fresh plant residues. This process is called mineralisation.

Crop nitrogen demand is related to actual yield, which is determined by seasonal conditions including the amount and timing of growing season rainfall. As the water-holding capacity of WA soils fluctuates, N crop use efficiency is highly variable also. There has generally been a poor relationship between pre-sowing soil test N and wheat and canola yield response. The pattern of crop demand for N during the growing season also has to be considered. The highest demand is when the crop is growing most rapidly.

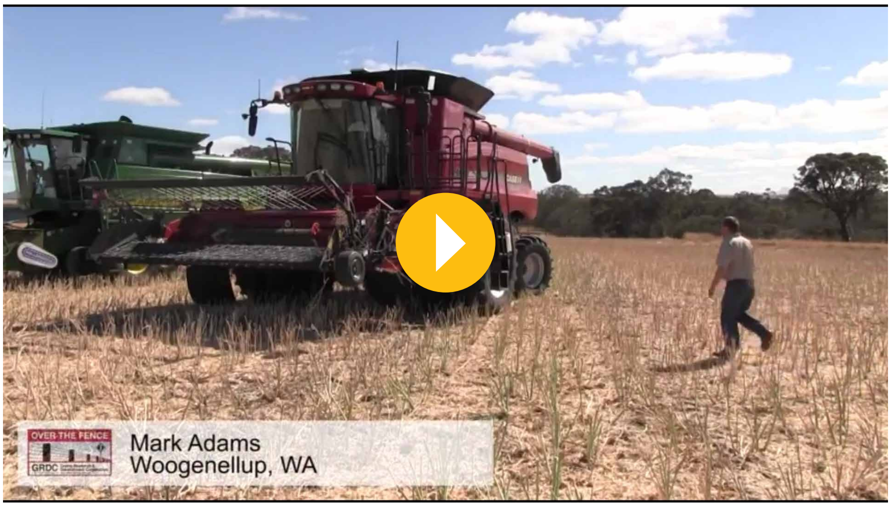
In-crop soil sampling can help identify how much nitrogen is being mineralised, but this is generally not practical. Surrogate measurements of crop nitrogen using crop sensors are a more practical alternative. Consequently, predicting N supply to crops is complex.

In WA, nitrogen fertiliser recommendations are based around a budgeting approach using a series of relatively simple, well developed equations. These equations attempt to predict the soil processes of mineralisation, immobilisation, leaching, volatilisation, denitrification and plant uptake. They are built into models such as Yield Prophet and Select Your Nitrogen (SYN). [18]

17 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Nitrogen–Western Australia. http://www.soilquality.org.au/factsheets/mineral-nitrogen

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

WATCH: Over the Fence West: Yield Prophet delivers fertiliser cost savings.



The N used in commercial fertilisers is particularly soluble for easy uptake and assimilation by plants. Because of the simplicity of its storage and handling, N can easily be applied when plants need it most (Figure 4).

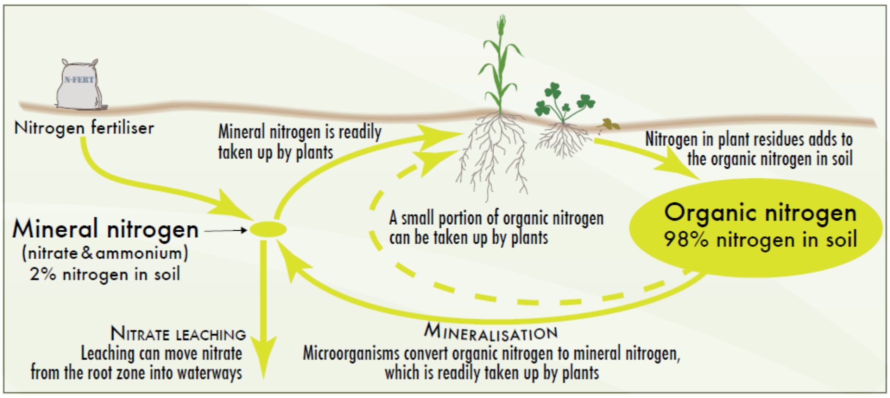


Figure 4: *The soil nitrogen cycle showing the role of mineralisation in making organic nitrogen in soil available for plants to take up.*

Source: Soilquality.org

WATCH: GCTV14: Nitrogen deficiency.

5.7.1 Chickpeas and nitrogen

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. [19]

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 3,234 kg N/t.* [20]

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

5.7.2 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. 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 remobilise 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 reduces branching. Plants have fewer flowers. Fewer pods are formed resulting in poor yields.

What to look for

1. When nitrogen supplies become restricted the older leaves display deficiency symptoms first.
2. The entire plant appears chlorotic, while older leaves turn more yellow than upper leaves (Figure 5).
3. Pink pigmentation develops on the lower part of the stem (Figure 6 left).
4. In prolonged deficiency conditions, the lower leaves turn yellow with reddish pink margins and a pink colouration develops on the lower stem (Figure 7).
5. In the later stage, the yellow older leaves turn white and drop prematurely (Figure 6 right). [21]

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19 W Hawthorne, W Bedggood. (2007). Chickpeas in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpeas-SA-Vic.pdf

20 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

21 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

Figure 5: *Nitrogen-deficient crop in foreground compared with nitrogen-fertilised crop behind.*

Source: CABI. Photo: Dr P Kumar

Figure 6: *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: CABI. Photo: Dr P Kumar

Figure 7: *Plant showing bottom leaves white, middle leaves yellow and top leaves green.*

Source: CABI. Photo: Dr P Kumar

5.7.3 Yield potential and nitrogen requirement

Nitrogen requirement of cereal crops is driven by yield potential, where every tonne of grain produced requires 40–50 kg/ha of N.

- Cereal crops access nitrogen from three major pools:
- **Stable Organic Nitrogen** (SON) is released slowly throughout the season, and is by far the largest nitrogen source in the soil. Approximately 2% of SON becomes available to crops during the season.
- **Residue Organic Nitrogen** (RON) is mineralised rapidly into NH4+ and NO3-, and is highest following legume crops.
- **Fertiliser Nitrogen** is applied to a crop by growers where the above sources cannot meet the needs of the crop.

Due to the number of different nitrogen sources accessible to the crop, it is best to use models to gauge nitrogen status in the soil. Most current models measure the following soil and crop attributes to determine soil nitrogen status/requirement:

- Yield potential — determines nitrogen demand of the crop.
- Total organic carbon (%) — gives indication of potential SON contribution.
- Rotation — characteristic of the last legume crop (RON).
- Soil type — gives indication of the potential for leaching.
- Rainfall — determines RON breakdown and contribution to leaching.

MORE INFORMATION

Soil Nitrogen supply factsheet.

Models that use this information are SYN (Select Your Nitrogen) from the Department of Agriculture and Food, Western Australia, and NuLogic from the commercial fertiliser company CSBP. [22]

Nitrogen application to chickpeas is often not worth the cost

The application of nitrogen to chickpea crops is not recommended, as yield benefits are unlikely to outweigh the cost of N application. Trials in eastern Australia, funded by the Grains Research and Development Corporation found that adding N to crops did not have any impact on yield, making the additional cost and potential loss in nitrogen fixing ability a double hit. The research looked at the impact of various nitrogen application rates: 0 kg/ha, 23 kg/ha and 46 kg/ha in the first year and 10 kg/ha and 50 kg/ha in the second year. Two application timings: at planting and in crop, and with or without Rhizobia inoculation, were also tested. None of the research sites showed any significant increase in yield from the application of N. In relatively low-yielding seasons there was no consistent impact on yield from the addition of nitrogen alone in chickpeas, across a wide range of starting soil nitrate levels. However, both 2012 and 2013 were low rainfall, poor yielding years and the project was initiated following observations during the wet, high yielding season of 2011 that paddocks with high N levels were yielding best. Significant yield increases would need to be seen to offset the cost of the fertiliser and the lost N fixation, with on average about 100-160 kg/ha of additional grain needed to offset nitrogen fertiliser cost and lost nitrogen fixation. [23]

5.8 Phosphorus

Key points:

- Phosphorus (P) is one of the most critical and limiting nutrients in agriculture in Western Australia. However, due to phosphorus management, most soils across the WA wheatbelt now exceed critical levels for soil P. [24]
- 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 in 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, particularly Western 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 development. Complex soil processes influence the availability of phosphorus applied to the soil, with many soils able to 'tie up' phosphorus, making it unavailable to plants. The soil's ability to do this must be measured when determining requirements for crops and pastures. [25]

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 amount of P will need to be replaced, unless soils are already high in P. Higher quantities may be needed to build up soil fertility or overcome soil fixation of phosphorus.

22 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program..Nitrogen–Western Australia. http://www.soilquality.org.au/factsheets/mineral-nitrogen

23 M Thomson. (2014). Adding Nitrogen to chickpeas is a double hit. GRDC. https://grdc.com.au/Media-Centre/Media-News/North/2014/02/Adding-nitrogen-to-chickpeas-is-a-double-hit

24 J Paterson. (2014). Ground Cover Supplement: Crop nutrition: region by region. GRDC.

25 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Phosphorus – Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

Chickpea is 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 P. This is equivalent to 80–186 kg/ha of single super or 40–95 kg/ha of double super. [26]

Chickpea is adapted to alkaline soils with high levels of unavailable P, and has evolved methods of extracting P from the soil (along with some other nutrients) 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 Zn will be required in most long-fallow situations (fallows longer than 10 months) where soil VAM levels may be low. [27]

Chickpea is considered highly dependent on AMF to reach yield potential, so yield reduction of 60–80% can occur in low AMF situations. [28]

High AMF situations

Where soil AMF levels are moderate to 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 9), or after crops such as canola that do not host AMF growth. In these conditions of low AMF (long fallows of over 8–12 months), chickpea is very responsive to applied P and Zn. Although chickpea 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 9: *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 10 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.

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

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

28 Pulse 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.

Table 10: *Effect of fallow length and fertiliser on chickpea growth.* [29]

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 (6 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. [30]

WATCH: GCTV13: Phosphorus deficiency.

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. 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 that the optimum time for P fertiliser application is before or during seeding. [31]

What to look for

1. Affected stems develop a reddish purple pigmentation that intensifies and becomes darker in prolonged deficiency conditions (Figure 8).

29 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

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

31 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program..Phosphorus–Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

2. In phosphorus deficient plants the top edges and upper surface of the leaflets exhibit reddish purple discolouration (Figure 9). [32]

Figure 8: *Plant showing dark green leaves with reddish purple disclouration in older leaves.*

Source: CABI. Photo: Dr P Kumar

Figure 9: *Purpling appearing on edges of leaflets (left) through to purple pigmentation spreading inwards to cover upper surface of leaflets (right).*

Source: CABI. Photo: Dr P Kumar

5.8.2 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 10). In the water soluble form phosphorus is not stable, and rapidly reacts in the soil (principally

32 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

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. [33]

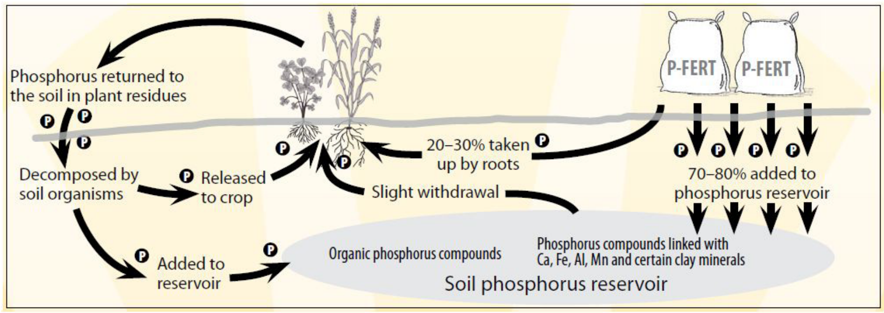

Figure 10: *The phosphorus cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited*

Glendinning, 2000. Source: The National Soil Quality Monitoring Program

5.8.3 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). [34]

5.8.4 Phosphorus retention and removal

Phosphorus that is not removed from the soil system remains as:

1. undissolved in fertiliser granules;
2. adsorbed by the soil; or
3. 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 adsorb phosphorus, giving increased effectiveness of subsequent applications.

Each crop species will remove different amounts of phosphorus from soil following harvest (see Table 1), which must be accounted for during nutrient budgeting.

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33 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Phosphorus—Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

34 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Phosphorus—Western Australia. http://www.soilquality.org.au/factsheets/phosphorus.

5.8.5 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. [35]

5.8.6 Soil P testing

The Soil P test needs to be interpreted in association with the soil's P sorption 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 0–10 cm soil layer and accumulate in the layers below 10 cm.

For lupins (pulse variety) grown in the northern agricultural region of WA, critical values are 8 mg P/kg for grey sands and 22 mg P/kg for yellow sands (both 0–10 cm). For lupins grown in the central and southern agricultural regions, critical values are 9 mg P/kg for grey sands and 30 mg P/kg for yellow sands (0 to 10 cm). However, a single critical value of 9mg P/kg is suitable for all soil types and regions when a sampling layer of 0–30 cm is used. [36]

5.9 Sulfur

Sulfur (S) is needed at higher rates for chickpea than some other crops. Use 'grain legume' fertilisers. If the paddock has a history of single super 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 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. [37]

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 when double-cropping chickpeas after high-yielding crops.

35 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Phosphorus—Western Australia. http://www.soilquality.org.au/factsheets/phosphorus.

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

37 GRDC (2014) Crop Nutrition Fact Sheet–Western Region. Soil Testing for crop nutrition. http://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 (Figure 11, 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 (Figure 11, right) and the entire plant can turn chlorotic. [38]

Figure 11: *Yellowing intensified on younger leaflets (left). Leaflets showing uniform yellowing (right).*

Source: CABI. 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 due to sulfur removal rates. [39]

IN FOCUS

Growth, nitrogen fixation and nutrient uptake by chickpea 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 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 & 30 kg S ha -1) of S from two sulfur S sources (gypsum and 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 protein content. Application of

38 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

39 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

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 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. [40]

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 (0–10 cm) for K is defined across all soil types as 41 mg K/kg to achieve a relative yield of 90% (for wheat).

When interrogating by soil type, loams have a higher critical value of 49 mg K/kg. The critical soil K test value for lupins grown on grey sands is 25 mg K/kg (0–10 cm) to achieve 90% of maximum yield. [41]

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 bean and chickpea 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 first plus second 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 first plus second leaf petioles and 2.1–2.2% in whole shoot of chickpea. [42]

40 M Islam, S Mohsan, S Ali, R Khalid, F Ul-Hassan, A 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).

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

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

5.10.1 Symptoms

Figure 12: *Tips of leaflets show brown necrotic patches and eventually die.*

Photo: Michael Bell, QAAFI

Figure 13: *Margins and tips of lower leaves show chlorosis.*

Photo: 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. [43]

5.11 Micronutrients

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.

5.11.1 Zinc

Chickpea is considered to have a relatively high demand for Zinc (Zn), 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 Zn levels are likely to be deficient.

Chickpea is prone to Zn deficiency. Low or marginal Zn 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 last 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 can be applied by spray to the soil, in furrow, coated on granular fertiliser or as a foliar spray. [44]

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

Symptoms

- 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 (Figure 14, left).
- In severe deficiency, bronzing and necrosis occurs on the leaflets (Figure 14, right). [45]

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43 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

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

45 P Kumar, P, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

Figure 14: *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: CABI. Photo: Dr P Kumar

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.

AMF are extremely important to Zn nutrition in chickpea, and large responses can be expected where AMF levels have become depleted due to long fallows (over 8–10 months).

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.

Seed treatments

Zinc seed treatments may be a cost-effective option where soil P levels are adequate but Zn levels are likely to be deficient:

- Broadacre Zinc (Agrichem): contains 650 g/L of Zn and is applied as 4 L product/t seed. Pre-mix with 1 L water prior to application. To minimise damage to the rhizobia, the Broadacre Zinc treatment needs to be applied first and then allowed to dry before applying the inoculum. Broadacre Zinc is compatible with Thiraflo or P-Pickel T and can be mixed with either product to treat chickpea seed in the one operation.
- Teprosyn Zn (Phosyn): contains 600 g/L of Zn and is applied as 4 L product/t seed. Pre-mix with 2–3 L water to assist coverage.

Fertilisers applied at sowing

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

Foliar zinc sprays

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. [46]

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). [47]

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 is 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. A map of potentially boron deficient soils in Western Australia is given in Figure 15.

46 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited

47 D Hall. The National Soil Quality Monitoring Program. Boron–Western Australia. http://www.soilquality.org.au/factsheets/boron

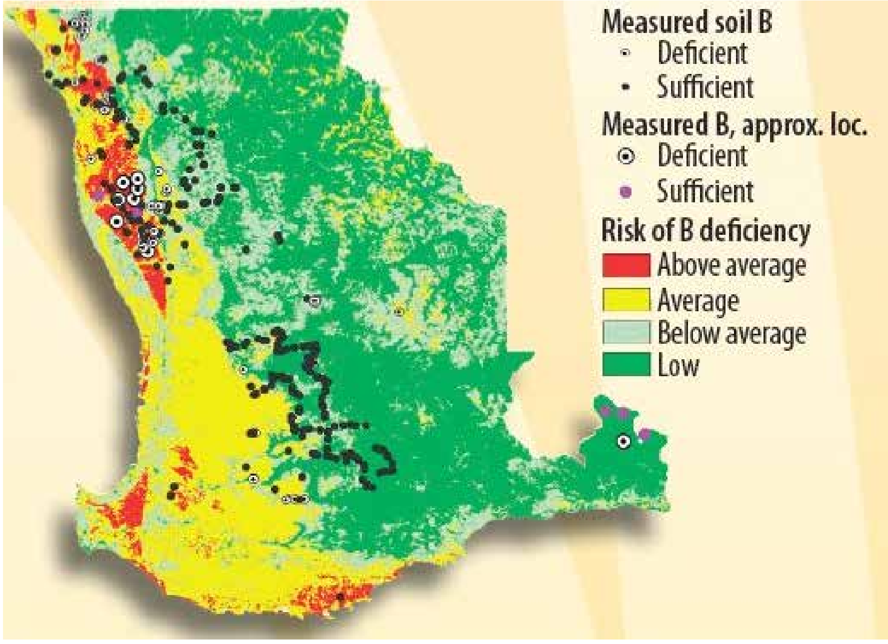

Figure 15: *Areas within south-western Australia cropping region believed to be at risk of boron deficiency based on surface geology, topsoil pH and clay content*

Adapted from Wong et al., 2005. Source: The National Soil Quality Monitoring Program

5.11.3 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.

Boron toxicity in Australia is mainly confined to the low rainfall (less than 550 mm per year) Mallee vegetation communities of Western Australia, South Australia and Victoria. The soils typically contain highly alkaline (pH greater than 8) and sodic clay subsoils which are poorly leached and have boron concentrations greater than 12 mg-B/kg of soil. Often boron toxic soils have formed from marine sediments or boron rich minerals including tourmaline. Symptoms of boron toxicity in barley are chlorotic and necrotic lesions in older leaves, whereas in wheat there are few visual symptoms. Soils with potentially high levels of boron in WA are shown in Figure 16.

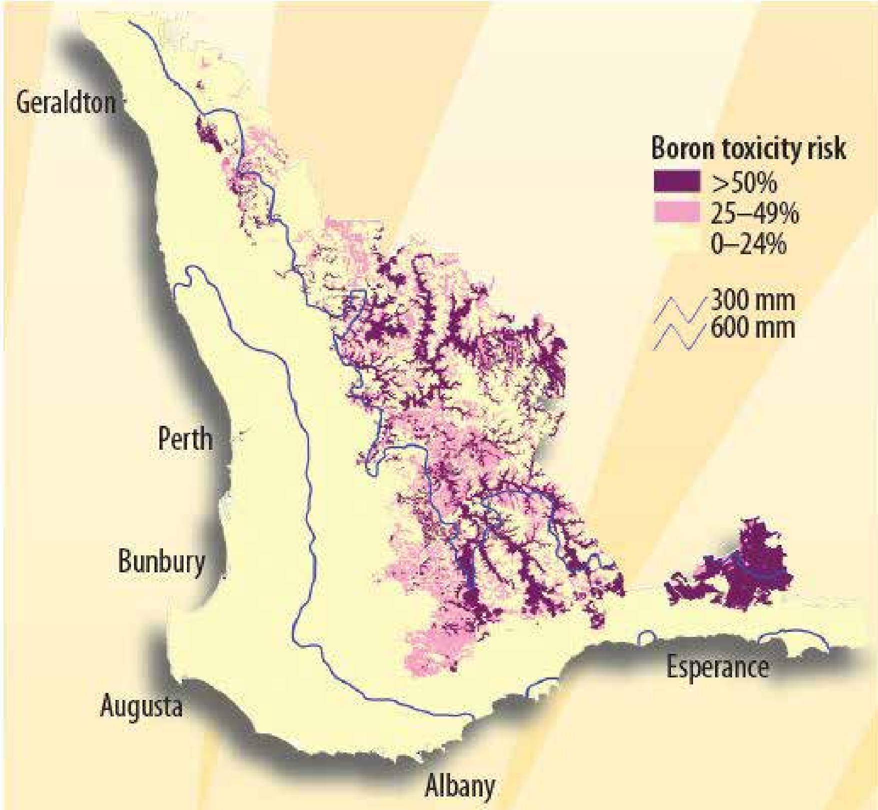

Figure 16: *Areas in Western Australian cropping region prone to boron toxicity.*

Source: The National Soil Quality Monitoring Program

Chickpea is 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 (Figure 17). There appears to be little difference in reaction between current varieties. [48]

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

Figure 17: *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. 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 near Esperance, WA, 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 toxicity. Grain with more than 3 mg-B/kg is likely to have been grown in boron toxic soils. [49]

5.11.4 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. [50]

49 D Hall. The National Soil Quality Monitoring Program. Boron–Western Australia. http://www.soilquality.org.au/factsheets/boron

50 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

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.

Iron deficiency is observed occasionally in alkaline, high-pH soils. It is usually associated with a waterlogging event following irrigation or heavy rainfall, and is attributed to interference with Fe 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. [51]

Symptoms

- Plants display deficiency symptoms first on younger leaves which turn bright yellow then white, while older leaves remain dark green (Figure 18).
- 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. [52]

Figure 18: *Leaflets of younger leaves are uniformly bright yellow to white, while older leaves remain dark and healthy.*

Source: CABI. Photo: Dr P Kumar

MORE INFORMATION

Crop nutrition Factsheet

Detecting and managing trace element deficiencies in crops

5.12 Nutritional deficiencies

Many soils in the cropping zone of south-western Australia are deficient in macro and micronutrients in their native condition. Plants require a number of nutrients to successfully grow and produce a crop. Western Australia's weather conditions can result in poor soil fertility and limited water supply which restrict a plants ability to uptake and use nutrients. To help identify nutritional deficiencies, see the GRDC Winter Cereal Nutrition: the Ute Guide.

5.13 Green and Brown Manuring

Green manuring and brown manuring are practices where plant material is returned to the soil to improve soil fertility, conserve soil water, reduce weed and disease burdens, and increase soil organic matter. These practices can be included as part of carbon farming, given their potential to increase soil organic matter. Increased stored soil organic carbon (SOC) would help to offset greenhouse gas emissions, increase farm productivity and potentially create offsets under the Emissions Reduction Fund (ERF). Green manuring has a very long history of managing weeds and building soil

51 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

52 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

fertility in systems where herbicides are not an option or not available, such as in organic farming systems.

The Department of Agriculture and Food, Western Australia (DAFWA) has published fact sheets on green and brown manuring, which show a number of benefits and practicalities of these farming approaches. More farmer experiences, research and field trial information are available on the Western Australian No-Tillage Farmers Association (WANTFA) website.

Practicalities to consider include:

- timing
- the crop species used to renovate the paddock
- the approach to maximising seed kill
- monitoring and managing regrowth
- economics
- the long-term benefits to be achieved.

Loss of income in the year that the practice is conducted must be considered, but this is likely to be offset by yield and quality benefits in the subsequent cropping year.

5.13.1 Outline of procedure

Green manuring incorporates green plant residue into the soil with a cultivation implement, commonly an offset disc plough. It aims to kill weeds and control seedset while building soil organic matter and nitrogen status. More than one tillage pass may be required for a successful kill, and cultivation may lead to losses of soil organic matter and cause soil structure damage.

Brown manuring is a 'no-till' version of green manuring, using a non-selective herbicide to desiccate the crop (and weeds) at flowering instead of using cultivation. A follow-up treatment may be required to control survivors. The plant residues are left standing, helping to retain surface cover and soil structure. Soil organic matter is increased.

A variation on brown manuring is mulching, where the crop or pasture is mowed, slashed or cut with a knife roller and the residue is left lying on the soil surface. This maximises soil surface cover to reduce wind erosion and helps to reduce soil moisture loss through evaporation. However, residues may break down more rapidly than during brown manuring because of the increased contact with soil and smaller pieces.

In Western Australia, pulses are generally the preferred crop to grow for green manuring practices as they improve the nitrogen status of the soil, and the potential foregone profit is lower relative to cereals and canola. Green manuring pulse crops, however, carries the risk of increased nitrous oxide ($N_2 0$) emissions, discounting increases in soil carbon sequestration. In some locations, it may be possible to grow a summer crop—for example, broad-leafed plants such as sunflower and safflower or grasses such as sorghum and millet—for green manuring purposes, especially on sandplain soils and in higher rainfall areas. However, high carbon to nitrogen (C:N) ratios may tie up nitrogen and depress subsequent yields.

5.13.2 Benefits

- The SOC content of soils in Western Australian cropping land is low—between about 1% and 4% with a mean of about 2% . [53] Manuring can help increase SOC.
- Improved soil fertility (largely observed in leguminous green manures) achieved by building soil organic matter and nutrient status, and increasing buffering capacity to moderate changes in pH.
- Reduced weed burdens, particularly when herbicides are not an option or effective, or a break is required.

53 Australian Soil Resource Information System (ASRIS), http://www.asris.csiro.au/methods.html

- Increasing soil organic matter to improve soil structure and provide a protective cover for the soil surface: this increases water infiltration and retention, reduces wind and water erosion, and reduces the impact of extreme temperatures. Conserving soil water and disease control in high rainfall environments are also major benefits.

5.13.3 Risks

- There is limited data clearly quantifying the change in SOC linked solely to manuring practices that could be used to calculate a potential carbon sequestration value.
- While most farmers have the appropriate equipment and tools (for example, a tractor, sprayer and some offset disks) to undertake green or brown manuring, others will incur costs when purchasing more specialised machinery (for example, stubble rollers and mulchers).
- There will be a revenue loss from not cropping the paddock in the year of manuring, but this may be offset in future years if improved soil quality increases the performance of subsequent crops.
- These practices will likely be part of rotational cropping management for the paddock, making it difficult to isolate the component(s) of the farming system impacting on soil organic change.
- Green manuring (ploughing in) can result in increased methane production through anaerobic decay.

Western Australian trials (three sites) have shown soil organic content in the topsoil increasing from an average value of 1.41% to 1.81%, 2.19% and 2.11% after one, two and three years of green manuring respectively. [54] The decline in the third year was due to dry conditions, which reduced the amount of biomass returned to the soil via the third green manure crop. The Western Australian No-Tillage Farmers Association (WANTFA) is conducting ongoing field trials, such as investigating the impact of cover crops that are knife rolled, measuring changes over a six year period. [55]

5.13.4 Current level of adoption

There is no adoption for specifically sequestering carbon. The limited data on the current level of adoption of these farming practices suggests that it is more often opportunistic rather than being a routine part of the agricultural system, often associated with herbicide resistance problems, degraded paddocks or failed crops. There is increasing interest in these farming systems however, due to increasing awareness of the benefits to soil quality and ecosystem services. [56]

The practices may be more widely adopted as the goal of increasing SOC improves soil quality and brings economic benefits, without the need to sell carbon credits. Adoption solely for carbon credits is probably not viable, but green or brown manuring could be one component of the overall farming system. [57]

54 F Hoyle, L Schulz, (2003). Restoration of paddock productivity through renovation cropping, in *DAW 628 trial results*, appendix 3, GRDC final report DAW 628.

55 Western Australian No-Tillage Farmers Association (WANTFA), 'Long term no-till farming systems "improving the quality of no-till",' http://www.wantfa.com.au/index.php?option=com_content&view=article&id=77&Itemid=73

56 K Broos, J Baldock, (2008). Building soil carbon for productivity and implications for carbon accounting, in *2008 South Australian GRDC Grains Research Update.*

57 DAFWA (2015) Carbon farming in WA–Green and brown manuring as part of carbon farming. https://www.agric.wa.gov.au/sites/gateway/files/CFWANo%207web%202015.pdf