



SOUTHERN

FEBRUARY 2016

GRDC™ GROWNOTES™



GRDC™

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

WHEAT

SECTION 5

NUTRITION AND FERTILISER

DECLINING SOIL FERTILITY | BALANCED NUTRITION | UNDERSTANDING
SOIL PH | HIERARCHY OF CROP FERTILITY NEEDS | CROP REMOVAL RATES
| SOIL TESTING | PLANT AND/OR TISSUE TESTING FOR NUTRITION LEVELS
| NITROGEN | PHOSPHORUS | SULFUR | POTASSIUM | MICRONUTRIENT
DEFICIENCIES

SECTION 5

Nutrition and fertiliser

More information

[GRDC Ute Guide: Winter cereal nutrition](#)

[BCG: Current GRDC-funded projects. More Profit for Crop Nutrition \(MPCN II\): Extension and training \(Southern Region\)](#)

[GRDC Fact Sheets: Better fertiliser decisions for crop nutrition](#)

[NSW DPI: BFDC Interrogator](#)

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[GRDC Update Papers: Assessing canopy management in CTF systems with farmer machinery](#)

[GRDC: Crop nutrition news](#)

With the more frequent use of opportunity cropping, improved farming techniques, and higher yielding varieties, nutrition programs should be reviewed regularly.

Nutrient deficiencies are common for nitrogen (N), phosphorus (P), potassium (K) and zinc (Zn), while sulfur (S), copper (Cu) and molybdenum (Mo) may be also be lacking in some soil types and growing areas. ¹

When fertiliser prices peaked in 2008, questions were raised about the cost-effectiveness of these inputs. New information was sought on best practice for yield and profitability. The result was the Grains Research and Development Corporation's (GRDC) More Profit from Crop Nutrition initiative. ²

To read about progress made under the program, download: [Ground Cover Issue 97 Supplement: More profit from nutrition.](#)

5.1 Declining soil fertility

The natural fertility of cropped agricultural soils is declining over time (Figure 1). Grain growers must continually review their management programs to ensure the long-term sustainability of high-quality grain production. Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils.

Paddock records, including yield and protein levels, fertiliser test strips, crop monitoring, and soil and plant tissue tests all assist in the formulation of an efficient cropping program.

Although crop rotations with grain legumes and ley pastures play an important role in maintaining and improving soil fertility, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed.

The yield potential of a crop will be limited by any nutrient the soil cannot adequately supply. Poor crop response to one nutrient is often linked to a deficiency in another nutrient. Sometimes, poor crop response can also be linked to acidity, sodicity or salinity, pathogens, or a lack of beneficial soil microorganisms. ³

¹ DAF Qld (2012) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

² M Blumenthal, I Fillery (2012) More profit from crop nutrition. GRDC Ground Cover Supplement Issue 97, March–April 2012, <http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-issue-97-MarApr-2012-Supplement-More-profit-from-nutrition/More-profit-from-crop-nutrition>

³ DAF Qld (2010) Nutrition management. Overview. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>



Figure 1: The natural fertility of cropped agricultural soils is declining over time.

5.2 Balanced nutrition

To obtain the maximum benefit from investment, fertiliser programs must provide a balance of required nutrients. There is little point in applying enough N if P or Zn deficiency is limiting yield. To make better crop nutrition decisions, growers need to consider the use of paddock records, soil tests and test strips. This helps to build an understanding of which nutrients the crop removes at a range of yield and protein levels.

The use of paddock grain protein to detect N deficiency is well established for wheat and barley. Grain protein lower than these levels is likely to indicate loss of yield due to inadequate N supply. Wheat with a protein level >14% has had its yield limited by lack of moisture.

Monitoring of crop growth during the season can assist in identifying factors such as water stress, P or Zn deficiency, disease or other management practices responsible for reducing yield.⁴

5.2.1 Paddock records

Paddock records help to:

- establish realistic target grain yield and protein levels prior to planting;
- modify target yield and protein levels based on previous crop performance (yield and protein), planting soil moisture, planting time, fallow conditions, expected in-crop seasonal conditions and grain quality requirements;
- determine appropriate fertiliser type, rate and application method; and
- compare expected with actual performance per paddock and modify fertiliser strategies to optimise future yield and protein levels.

The longer paddock records are kept, the more valuable they become in assessing future requirements.⁵

⁴ DAF Qld (2010) Nutrition management. Overview. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>

⁵ DAF Qld (2010) Nutrition management. Overview. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>

5.3 Understanding soil pH

A soil pH in calcium chloride (CaCl_2) of 5.2–8.0 provides optimum conditions for most agricultural plants. All plants are affected by extremes of pH, but there is wide variation in their tolerance of acidity and alkalinity. Some plants grow well over a wide pH range, whereas others are very sensitive to small variations in acidity or alkalinity.

Microbial activity in the soil is also affected by soil pH, with most activity occurring in soils of pH 5.0–7.0. Where extremities of acidity or alkalinity occur, various species of earthworms and nitrifying bacteria disappear.

Soil pH affects the availability of nutrients, and affects how the nutrients react with each other.⁶

The pH mapping process can deliver immediate lime savings of 20–60% with an average saving of 30%. A 10% lime saving is generally required to cover the cost of the mapping process.⁷ See more in the GRDC Update Paper: [pH-mapping and variable rate lime—50,000 plus hectares of experience](#).

At low pH, beneficial elements such as Mo, P, magnesium (Mg), S, K, calcium (Ca), and N become less available and others may become toxic (Figure 2). Maintain soil pH(CaCl_2) between 5.5 and 6.5 to achieve maximum P availability for wheat.⁸

For more information on crop-specific reactions to soil pH levels, download the New South Wales Department of Primary Industries leaflet: [Understanding soil pH](#).

⁶ B Lake (2000) Understanding soil pH. Acid Soil Management Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/167187/soil-ph.pdf

⁷ A Whitlock (2015) pH mapping and variable rate lime. GRDC Update Papers, 27 August 2015, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/pH-mapping-and-variable-rate-lime-50000-plus-hectares-of-experience>

⁸ B Lake (2000) Understanding soil pH. Acid Soil Management Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/167187/soil-ph.pdf

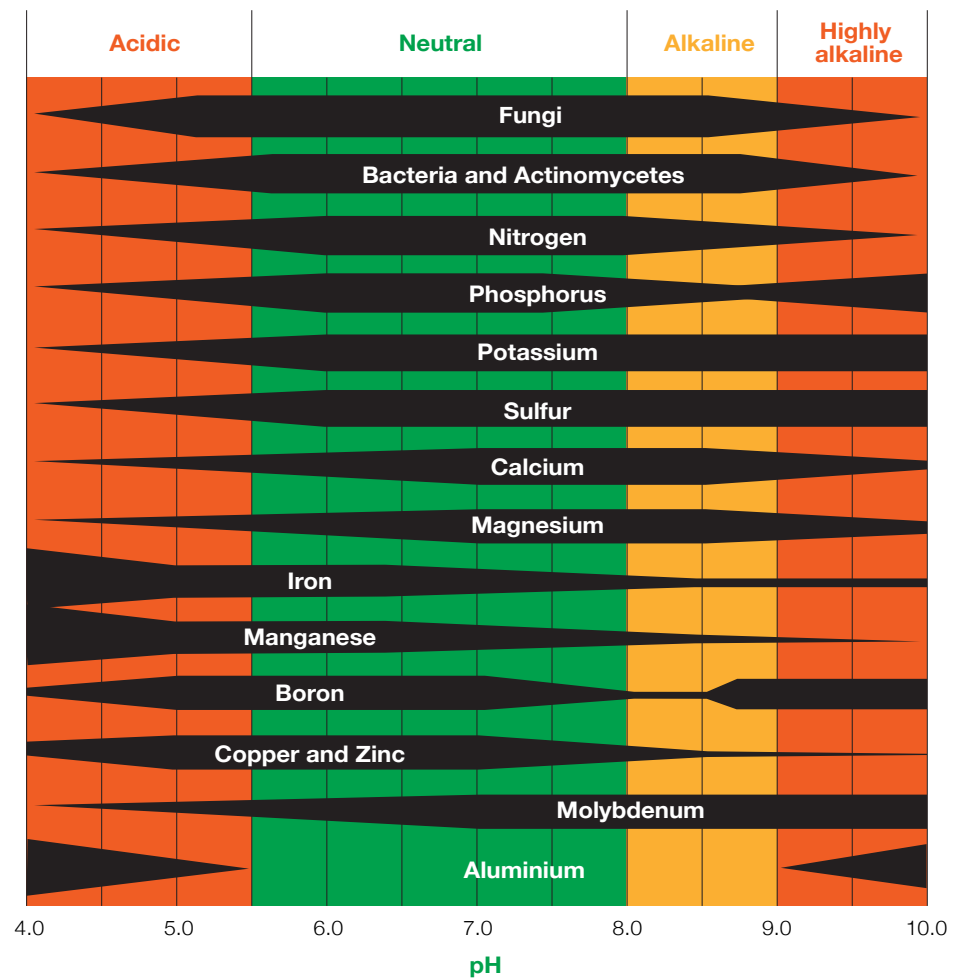


Figure 2: Effect of $\text{pH}(\text{CaCl}_2)$ on the availability of soil nutrients. (Source: after Trough)

The two main laboratory methods employed in Australia to determine pH use either CaCl_2 or water.

5.3.1 Soil pH in calcium chloride

This is the standard method of measuring soil pH in southern Australia. An air-dry soil sample is mixed with five times its weight of a dilute concentration (0.01 m) of CaCl_2 , shaken for 1 h, and the pH is measured by using an electrode. The results are usually expressed as $\text{pH}(\text{CaCl}_2)$.

5.3.2 Soil pH in water

Distilled water is used instead of 0.01 m CaCl_2 , and results are expressed as $\text{pH}(\text{H}_2\text{O})$. The $\text{pH}(\text{CaCl}_2)$ test is the more accurate of the two tests, because it reflects what the plant experiences in the soil. The values of $\text{pH}(\text{CaCl}_2)$ are normally lower than $\text{pH}(\text{H}_2\text{O})$ by 0.5–0.9. A useful, but not consistently accurate, conversion is to subtract 0.8 from the $\text{pH}(\text{H}_2\text{O})$ to obtain a $\text{pH}(\text{CaCl}_2)$ value. The difference between the methods can be significant when interpreting results and it is important to know which method has been used, especially if pH values derived some years apart are being compared to assess fluctuations.⁹

⁹ B Lake (2000) Understanding soil pH. Acid Soil Management Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/167187/soil-ph.pdf

5.4 Hierarchy of crop fertility needs

The hierarchy of crop fertility needs says there must be sufficient plant-available N to obtain a response to P, and there must be sufficient P for S and/or K responses to occur.¹⁰

Liebig's law of the minimum is a principle developed in agricultural science by Carl Sprengel (1828) and later popularised by Justus von Liebig. It states that growth is controlled not by the total amount of resources available, but by the scarcest resource (i.e. limiting factor) (Figure 3).¹¹

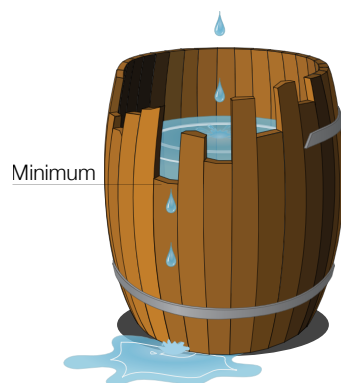


Figure 3: Liebig's law, or law of the minimum.

Additive effects of N and P appear to account for most of the aboveground growth and yield response.¹²

5.5 Crop removal rates

Ultimately, nutrients removed from paddocks will need to be replaced to sustain production. Table 1 illustrates the different levels of nutrients extracted in both irrigated and dryland scenarios. Growers need to adopt a strategy of programmed nutrient replacement based on yields and protein taken off paddocks.

Table 1: Average amounts of nutrients (kg/ha) removed by wheat crops

	Yield	N	P	K	Ca	Mg	S	Zn
Irrigated wheat grain	7000	125	24	35	3.5	10	3	200
Dryland wheat grain	2000	40	7	10	1.5	2.8	5.5	60

To attain optimum yields, an adequate supply of each nutrient is necessary. However, only a small proportion of the total amount of an element in the soil may be available for plant uptake at any one time. For nutrients to be readily available to plants, they must be present in the soil solution (the soil water), or easily exchanged from the surface of clay and organic matter particles in the root-zone, and be supplied when and where the plant needs it.

Temperature and soil moisture content affect the availability of nutrients to plants, and the availability of nutrients also depends on soil pH, degree of exploration of root systems, and various soil chemical reactions, which vary from soil to soil. Fertiliser may be applied in the top 5–10 cm, but unless the soil remains moist, the plant will not be able to access it. Movement of nutrients within the soil profile in low-rainfall areas is

¹⁰ D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers, 7 March 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs>

¹¹ Liebig's law of the minimum. Wikipedia, http://en.wikipedia.org/wiki/Liebig's_law_of_the_minimum

¹² D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers 7 March 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs>

generally low, except in very sandy soils, and some nutrients, such as P and Zn, are relatively immobile in the soil.

Lack of movement of nutrients, combined with current farming methods (e.g. no-till), is resulting in stratification of these nutrients, with concentrations building up in the surface of the soil where they are not always available to plants. Deep sowing is done into moisture that is below the layer where nutrients have been placed or are stratified, and this has implications for management and fertiliser practices.¹³

5.6 Soil testing

Soil testing and professional interpretation of results should now be an integral part of all management strategies. Soil tests estimate the amount of each nutrient available to the plant rather than the total amount in the soil. Valuable information obtainable from a soil test includes current nutrient status, acidity or alkalinity (pH), soil salinity (electrical conductivity, EC), and sodicity (exchangeable sodium percentage), which can affect soil structure.

Soil test information should not be used alone to determine nutrient requirements. It should be used in conjunction with test-strip results and previous crop performance to determine nutrients removed by that crop, and previous soil test records, to obtain as much information as possible about the nutrient status of a particular paddock.

Care must be taken when interpreting soil test results. Nutrients can become stranded in the dry surface layer of the soil after many years of no-till or reduced tillage, or deep nutrient reserves may be unavailable because of other soil factors such as EC levels, sodicity or acidity.¹⁴

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 crop demand as well as the ability to access nutrients
- zoning paddocks for variable application rates
- as a diagnostic tool, to identify reasons for poor plant performance

Soil test results are part of the information that support decisions about fertiliser rate, timing and placement.

To determine micronutrient status, plant tissue testing is usually more reliable.

5.6.1 Types of test

The soil tests for measuring N, P, K or S in the Southern Region are:

- bicarbonate-extractable P (Colwell-P)
- diffusive gradients in thin-films (DGT) for P
- bicarbonate-extractable K (Colwell-K)
- KCl-40 extractable S
- 1 m KCl-extractable inorganic N, which provides measurement of nitrate-N and ammonium-N

For determining crop N requirement, soil testing is only one part of the picture. Soil N availability and crop demand for N are both highly influenced by seasonal conditions.

¹³ DAF Qld (2012) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

¹⁴ DAF Qld (2010) Nutrition management—Overview. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>

More information

[GRDC: Soil testing for crop nutrition \(Southern Region\)](#)

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), EC, chloride and exchangeable cations (cation exchange capacity, CEC) including aluminium (Al).

5.6.2 Sampling depth

Soil sampling depth for most nutrient analyses is 0–10 cm. For N and S, which are highly mobile in the soil, 0–60 cm is recommended. There is increasing evidence of the value of assessing soil-based physicochemical constraints to production, including sodicity, salinity and acidity–Al, from both the surface and subsoil layers.

In some regions, evidence suggests that deep soil samples should be analysed for nutrients other than N. This is still not fully supported for the soils in the Southern Region. Deep sampling especially for S, EC and B to the depth of any root barriers is now carried out regularly.

To ensure that a sample is representative:

- Check that the soil type and plant growth is typical of the whole zone or paddock.
- Avoid areas such as stock camps, old fence lines and headlands.
- Ensure that each subsample is taken to the full sampling depth.
- Do not sample in very wet conditions or within 2 weeks after significant summer rain.
- Do not take shortcuts in sampling, such as taking only one or two cores, a handful, or a spadeful of soil; this will give misleading results.
- Avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers or other sources of nutrients (e.g. sunscreen, which can contain Zn).

Soils must be sampled to the correct depth. Sampling depths of 0–10 and 10–60 cm are generally used. The 0–10 cm sample should be used for a comprehensive soil test (all nutrients, cations, pH, EC, sodium). The 10–60 cm sample (or known rooting depth) is more commonly used to determine levels of N, S, EC and boron (or other nutrient constraints) and moisture. Sulfur testing at 0–10 cm is not as indicative of crop needs as 0–60 cm, and this is more so on sandy soils where leaching of S from the topsoil readily occurs. If subsoil constraints are suspected, pH, EC, sodium and chloride are tested at intervals (e.g. 30 cm) to 120 cm where possible.

5.6.3 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 that single value. The narrower the range the more reliable the data (Table 2).

The critical value indicates whether nutrient supply is likely to result in a crop yield response.

The values used to determine the soil test–crop response relationship have been derived from fertiliser rate trials, in which various fertiliser rates are applied and the crop yield response is measured. With many of these experiments, soil test values and crop responses can be graphed.

If the soil test value is less than the lower limit of the range, the site is highly likely to respond to an application of the nutrient.

For values within the critical range, there is less certainty about whether a response will occur. If a response does occur, it will likely be small. Growers must exercise judgement about the costs and benefits of adding fertiliser in the forthcoming season versus those

associated with no application. If the soil test is outside the critical range, fertiliser must be considered to maintain soil levels or to lower the risk of encountering deficiency.¹⁵

Table 2: Critical values and critical ranges (mg/kg) for the 0–10 cm sampling layer for 90% of relative yield¹⁶

Soil types are based on the Australian Soil Classification. For phosphorus, insufficient data are available to provide calibration criteria for diffusive gradients in thin-films (DGT)-P (check BFDC Interrogator). Insufficient sulfur data to measure 0–10 cm

Soil test	Crop	Soil type	Critical value	Critical range
Colwell-P	Wheat and barley	Vertosols	17	12–25
		Chromosols, Sodosols	22	17–28
		Brown/Red Chromosols	25	18–35
	Barley	Calcarosols	34	26–44
		Ferrosols	76	46–130
		All soils	18	16–19
Canola	All soils	24	21–28	
	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 (0–15 cm)	8.6
	Canola	NSW data (0–60 cm)	31	25–39

5.6.4 Test strips

Test strips allow you to fine-tune the fertiliser program. To gain the maximum benefit:

- Run them over a number of years; results from any single year can be misleading.
- Obtain accurate strip weights.
- Protein-test a sample of grain from each strip.
- Harvest strips before your main harvest, because the difference between the strips is more important than the moisture content.

When setting up a test strip area:

- Ensure that you can accurately locate the strips—a GPS reading would be valuable.
- Repeat each fertiliser treatment two or three times.
- Change only one product rate at a time.
- Separate each strip of fertiliser by a control or nil-fertiliser strip.
- Ensure that tests are done over a part of the paddock with a uniform soil type.
- Keep clear of shade lines, trees, fences, headlands and any known anomalies in the field.
- Ensure that the test strip area is ~100 m long, with each strip 1–2 header widths.

A number of local [Grower Groups](#) conduct nutrition trials.

¹⁵ GRDC (2014) Soil testing of crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, <http://www.grdc.com.au/GRDC-FS-SoilTestingS>

¹⁶ GRDC (2014) Soil testing of crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, <http://www.grdc.com.au/GRDC-FS-SoilTestingS>

Colour photographs of nutrient deficiencies can be found in: Grundon NJ (1987) 'Hungry crops: a guide to nutrient deficiencies in field crops', Department of Primary Industries, Queensland Government, Information series Q187002. ¹⁷

5.6.5 Rules of thumb

Choose the same soil test package each year (including methods); otherwise, comparisons between years will be useless. For example, do not use Colwell-P in one year, then DGT-P the next; the two tests measure different forms of available P in the soil.

If you do not use a standard approach to sampling, a comparison of the data between different tests will not be reliable. Aim for data that have the best chance of representing the whole paddock, and mix the sample thoroughly.

For monitoring, sampling needs to cover roughly the same area each time to ensure meaningful comparisons between years. Permanent markers on fence posts to mark a sampling transect, or a handheld GPS or your smartphone, will serve this purpose.

Soil-testing laboratories should be able to provide information on appropriate soil sampling and sample-handling protocols for specific industries and crop types. Refer to the [Australian Soil Fertility Manual](#) from CSIRO Publishing or download the GRDC Fact Sheet [Better fertiliser decisions for crop nutrition](#). ¹⁸

Utilise an ASPAC- and NATA-accredited testing service. The results are more likely to be statistically significant and have reduced variation between tests.

5.6.6 Soil testing for nitrogen

The approximate amount of N available in the soil can be determined by soil testing. Soil tests should be taken at various places in each paddock to a depth of 60 cm or to a known rooting depth. Primary wheat roots can grow to a depth of 2 m and can extract N from this level. ¹⁹

Test results are a great indication of N, but historical grain yield and protein levels from the paddock can also be used to assist N-requirement decision making. ²⁰

Environmental conditions, including temperature, time and rainfall events can affect starting soil N; therefore, it is important to test later in the summer or make adjustments to factor in mineralisation amounts as well as denitrification and leaching events if they occur.

Forms of N fertiliser

Nitrogen is available in four main forms:

1. Nitrate, e.g. ammonium nitrate, sodium nitrate, potassium nitrate
2. Ammonium, e.g. anhydrous ammonia, sulfate of ammonia, ammonium nitrate
3. Amide, e.g. urea
4. Organic, e.g. blood and bone, meat meal

It is important to choose the right product; some compositions are more suited to certain conditions than are others.

¹⁷ DAF Qld (2010) Nutrition management—Overview. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>

¹⁸ GRDC (2013) Better fertiliser decisions for crop nutrition. Crop Nutrition Fact Sheet, GRDC, 4 November 2013, <http://www.grdc.com.au/GRDC-FS-BFDCN>

¹⁹ NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Proccrop-wheat-growth-and-development.pdf

²⁰ DAF Qld (2010) Nutrition management—Overview. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>

More information

[GRDC Fact Sheets: Crop nutrition – phosphorus management](#)

Calculating N fertiliser application

If N fertiliser is required, the equation below can be used to obtain the quantity of fertiliser required:

Fertiliser product required (kg/ha) = rate of N required (kg/ha) x 100/% N in fertiliser product²¹

For example, if 40 kg N/ha is required, this rate of N can be supplied by applying 87 kg/ha of urea (46% N).

5.6.7 Soil testing for phosphorus

Colwell-P (bicarbonate-extractable P)

The Colwell-P test uses a bicarbonate (alkaline) extraction process to assess the level of readily available soil P. It was the original test for P response in wheat in northern NSW. It is used with the PBI to indicate the sufficiency and accessibility of P in the soil.

Soil available P by DGT (diffusive gradients in thin-films)

Present soil testing methods for assessment of available P overestimate available P on certain soil types (calcareous, acidic with high iron or Al). The DGT method has been established for assessment of available P in a wide range of Australian soils and it measures available P at more relevant chemical and physical soil conditions.

A database of DGT results with crop responses across southern Australia reveals a greater accuracy of available P measurement than with Colwell P with or without PBI interpretation. DGT has potential not only to measure the available P status but also to predict P rates required to maximise yields in a deficient scenario.

Phosphorus buffering index

The 'buffering capacity' of a soil refers to its ability to maintain P concentration in solution as the plant roots absorb the P. The PBI indicates the availability of soil P. The higher the value, the more difficult it is for a plant to access P from the soil solution.

Depth of testing for P

Soil sampling depth for most nutrient analysis (including P) is 0–10 cm. Phosphorus is relatively immobile in soils and P applied to the 0–10 cm layer generally remains in that layer, especially in no-till systems.²²

5.7 Plant and/or tissue testing for nutrition levels

Tissue testing is the best way to diagnose nutrient deficiencies accurately when a crop is growing, whether macronutrients, or micronutrients such as Zn and Cu.

The successful use of plant tissue analysis depends on sampling the correct plant part, at the appropriate growth stage. For example, the critical tissue P concentration changes with the age of wheat plants.

For these reasons, critical tissue concentrations should be associated specifically with defined stages of plant growth or plant part rather than growth periods (i.e. days from sowing). Growers are advised to follow laboratory guides or instructions for sample collection.

Plant nutrient status varies according to plant age, variety and weather conditions. The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small (Figure 4).

More information

[Soil Quality Fact Sheet: Soil phosphorus availability by DGT](#)

More information

[Soil Quality: South Australia—phosphorus buffering index](#)

[Research paper: A simple phosphorus buffering index for Australian soils](#)

²¹ DAF Qld (2012) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

²² GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, January 2014, <https://www.grdc.com.au/~media/34D1397472234B6F8B195732A963F047.pdf>

When applying fertiliser to treat a suspected deficiency, leave a strip untreated. Either a visual response (a yield difference <20% is difficult for the human eye to detect) or plot harvesting of the strips can allow you to confirm whether the micronutrient was limiting.²³

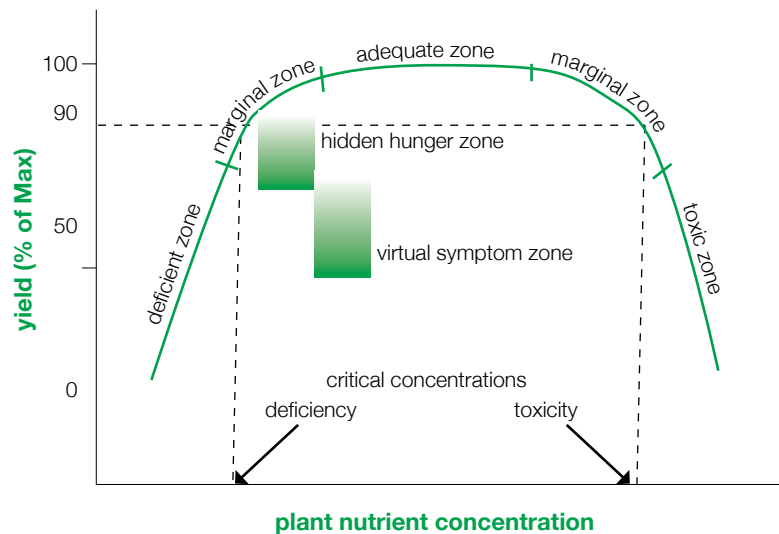


Figure 4: Generalised grain yield response curve to plant nutrient concentration.

5.8 Nitrogen

Predicting N supply to crops is complex. Nitrogen demand by the crop is related to actual yield, which is determined by seasonal conditions including the amount and timing of growing season rainfall.

There is generally a poor relationship between pre-sowing soil-test N and yield response of wheat and canola to applied N. This is usually due to the effect of stored water and in-season rainfall.

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 to identify how much N is being mineralised. Fertiliser recommendations for N are generally based around a budgeting approach, using a series of relatively simple, well-developed equations that estimate plant demand for N and the soil's capacity to supply N.

These equations are an 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). *Yield Prophet*[®] requires a detailed characterisation of the physical and chemical properties of the soil profile explored by the roots.²⁴

5.8.1 Nitrogen supply and grain protein content

Nitrogen is a primary constituent of protein; therefore, adequate soil N supply is essential for producing wheat with a high protein content. Supply of N is shaped by a number of factors in the farming system (Figure 5) and the N cycle (Figure 6).

²³ GRDC (2013) Micronutrients. Northern, Southern and Western Regions. Crop Nutrition Fact Sheet, GRDC, November 2013, <http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients>

²⁴ GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, January 2014, <http://www.grdc.com.au/GRDC-FS-SoilTestingS>

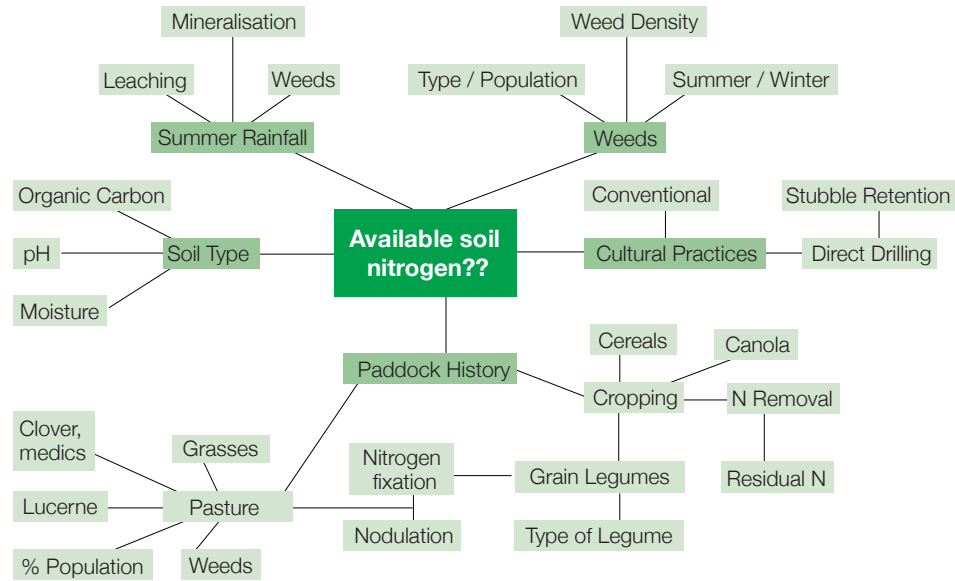


Figure 5: Factors influencing available soil nitrogen. (Source: Incitec Pivot Ltd)

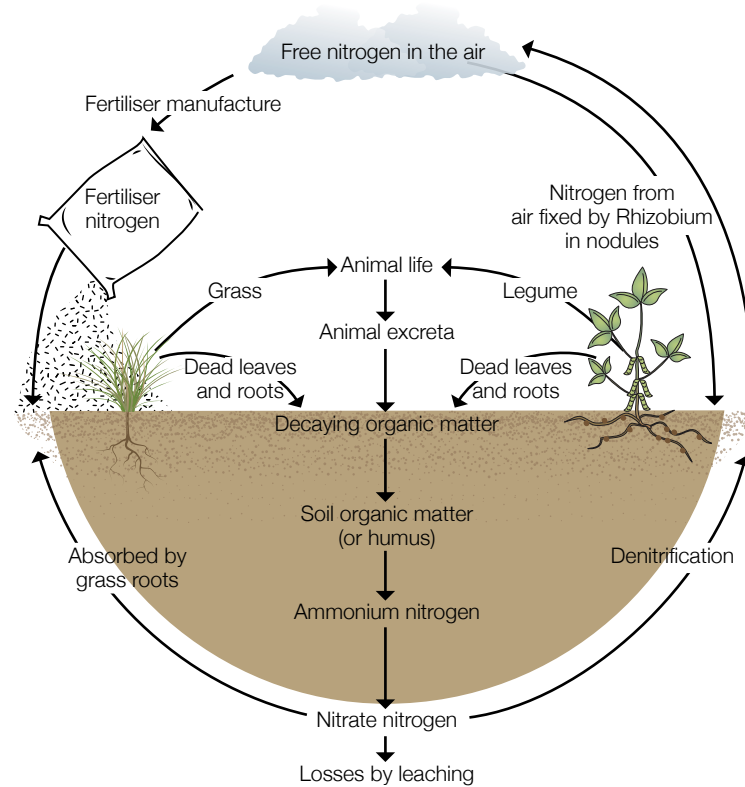


Figure 6: The soil nitrogen cycle.

Besides its role in plant growth, the availability of soil N at grainfill, along with soil moisture, is the key determinant of grain protein. The farmer has a high degree of control over N build-up and availability through the choice of crop sequences and management. The availability of N in the soil will be affected by many factors: soil organic matter, paddock history, soil type, moisture content, time of year, and tillage methods.

High yields are a drain on soil N. Conversely, low yield and summer rain to mineralise N can mobilise soil N for the next crop. Soil tests for N assessment should be done as close as possible to sowing time or during peak growth and at the same time each year.

Cropping advisors are a good source of support in determining fertiliser application strategies.²⁵

Grain protein is modified by the grain yield of the crop—increasing grain yield has a diluting effect on grain protein, i.e. yield and protein are inversely proportional (Figure 7). This explains why a larger proportion of the crop is of a high protein in drier seasons or seasons of low grain yield, whereas high yields can be produced but may be at a lower protein level in wetter years. Nitrogen fertility can be extremely variable from one year to the next.

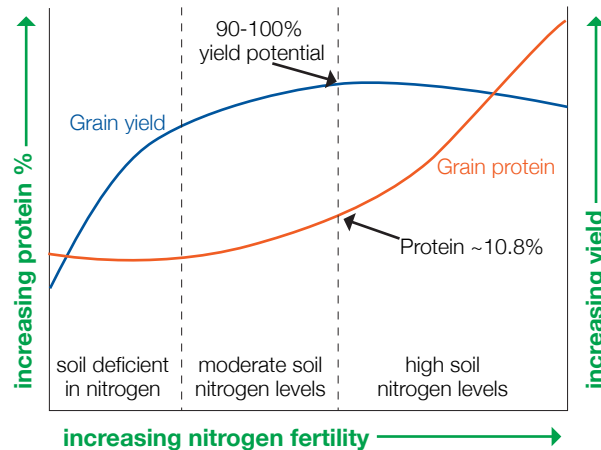


Figure 7: Relationship between grain yield and protein. (Source: Incitec Pivot Ltd)

More information

GRDC Update Papers:
[Where does fertiliser nitrogen finish up?](#)

5.8.2 Nitrogen deficiency symptoms

Description:

- Plants are pale green with reduced bulk and tiller formation (Figures 8 and 9).
- Symptoms first occur on oldest leaf, which becomes paler than other leaves, with marked yellowing beginning at the tip and gradually merging into light green.
- Other leaves begin to yellow and oldest leaves change from yellow to almost white.
- Leaves may not die for some time.
- Grain yield and protein levels are reduced.

Similar symptoms

Deficiencies of K and P show similar yellowing of oldest leaves, but these leaves die quickly. Reduced grain yield and protein levels may occur for other reasons.

²⁵ Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

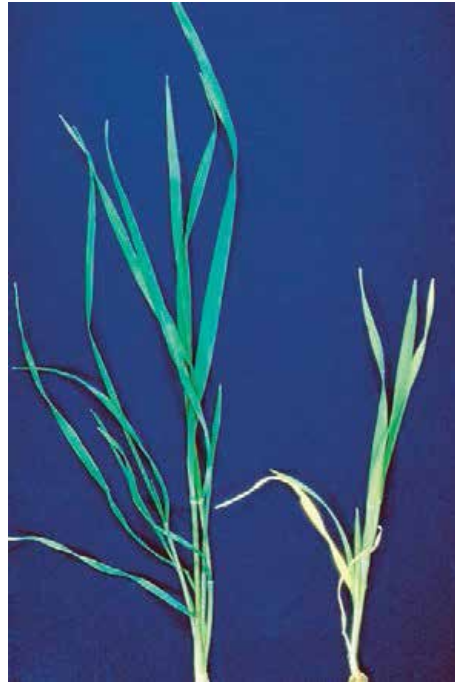


Figure 8: Adequate (left) and inadequate (right) nitrogen nutrition. (Photo: Mel Mason, Agriculture WA)²⁶



Figure 9: Inadequate nitrogen nutrition expressed as pale green plants with reduced bulk and tiller formation.

Contributing factors

Low soil N fertility and cold wet conditions reduce mineralisation and uptake of N. Low incidence of legumes in rotation reduces amounts of N₂ fixed. High N loss occurs by leaching in high-rainfall areas and sandy soils.²⁷

5.8.3 Nitrogen volatilisation and denitrification

Ammonia volatilisation can occur when urea is surface-applied without incorporation. After application, urea dissolves in water and, in the presence of urease, forms

²⁶ GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

²⁷ GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

ammonium ions (NH₄⁺). If there are insufficient adsorption sites at the soil surface for the ammonium ions, ammonia (NH₃) gas can form as the soil dries out, for example, in the heat of the day following overnight dew. Such losses are greatest in alkaline (high-pH) soils, in which hydroxyl (OH⁻) ions are present in high concentrations.²⁸

Many farmers practice pre-season broadcasting and in-season topdressing of wheat crops. Splitting N application between sowing and in-crop allows growers to lower their financial risk on fertiliser application by allowing seasonal conditions to drive decisions on how much to spend on N, but this can come at a cost of additional yield.

Most farmers try to apply fertiliser ahead of predicted rain, but what happens if rain does not fall as predicted? Is all of the N really lost to the air in 1 or 2 days? Literature from international research lists the range of measured losses from 0% to almost 100%, but very few instances of losses >~40% of that applied, with most studies finding only ~10% loss.

In the 2008 and 2009 GRDC Adviser Updates, researchers detailed the factors that drive the process of N volatilisation from fertiliser, along with the results of some laboratory incubation experiments.

The following is a brief summary of the many factors involved:

1. Soil pH. There is more loss at higher pH. A dissolving urea granule creates a high-pH zone.
2. Temperature. The hotter it is, the greater the potential for ammonia loss.
3. Soil moisture. Wet soil dissolves fertiliser but does not move N into the soil.
4. Calcium carbonate (CaCO₃). Lime in the soil reacts directly with ammonium sulfate, increasing loss.
5. Soil clay content. Clay in soils adsorbs ammonium-N, decreasing potential for loss.
6. Soil buffer capacity. Clays in soil absorb changes in soil pH.
7. Biological activity. Ammonium is converted to nitrate, which is safe from volatilisation.
8. Wind. Windy conditions at the soil surface lead to greater loss.
9. Rain. Rain moves dissolved fertiliser into contact with soil clays, away from wind.
10. Depth of fertiliser. Ammonia must be at the surface to volatilise. Incorporation reduces loss.
11. Crop canopy. Some ammonia in air can be re-absorbed by a growing crop canopy, and the canopy reduces the wind intensity at the soil surface.
12. Residues and litter. Residues can strand the fertiliser at the surface. Urease enzyme is present in residues.
13. Fertiliser type. Only the ammonium form is lost; urea converts to ammonium and nitrate forms, which are not volatilised.

²⁸ Incitec Pivot Limited, <http://www.incitecpivot.com.au/>

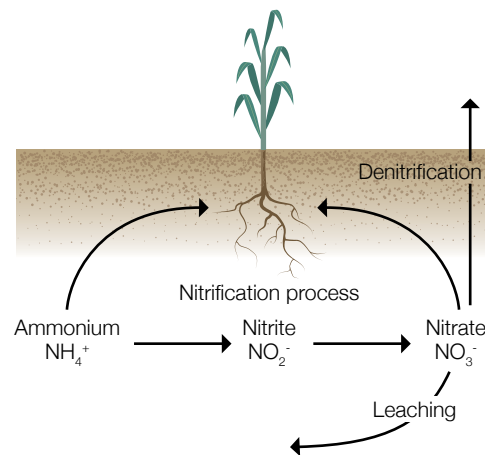


Figure 10: The nitrification process.

Saturated soil conditions between fertiliser application and crop growth can lead to significant N losses from the soil through denitrification (Figure 10). The gases lost can be nitric oxide (NO), nitrous oxide (N_2O) and di-nitrogen (N_2). Isotope studies in the northern grains region have found that these losses can be >30% of the N applied. Direct measurements of nitrous oxide highlight the rapidity of loss in this process.

Nitrogen losses from ammonium sulfate applications were less than from urea in both bare fallows and grass-based perennial pastures. However, ammonium sulfate should be avoided on soils with naturally occurring lime in the surface.²⁹

Research funded by GRDC and NSW DPI through a Northern Grower Alliance project (NGA0002) showed that delayed N reliably improved grain protein and maintained grain yield with applications up to early stem elongation, irrespective of the N fertiliser used.³⁰

5.8.4 Nitrogen-use efficiency

Efficient use of N is crucial to economic production of wheat. Over-application of N may increase susceptibility of the crop to disease and increase water use early in the growing season, creating excessive early growth, causing crops to 'hay off'. Insufficient N may limit grain yield, grain protein and subsequent profitability. Within a given season in a cereal crop, fertiliser rate and timing are the major tactical tools used for N management. Applications of N at sowing or up to the start of stem elongation drive greater crop biomass and grain yield response than late applications (around anthesis or Zadoks growth stage (GS) 61), which have little influence on grain yield but can drive a significant protein response.³¹

5.8.5 Plant-available (nitrate) N in the root-zone

Nitrogen in the plant-available, mineral form is a major driver of crop production. Almost all of the N taken up by crops is in the form of nitrate. The other mineral form, ammonium, is present in most soils at low levels.

In some soils, subsoil constraints will limit the root-zone to <1 m. In other soils that are particularly well structured, the root-zones of long-season or particularly vigorous crops can be as deep as 1.8 m.

²⁹ G Schwenke (2013) Nitrogen use efficiency. GRDC Update Papers, 16 July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency>

³⁰ G Schwenke, A Perfrement, W Manning, G McMullen (2012) Nitrogen volatilisation losses how much N is lost when applied in different formulations at different times. GRDC Update Papers 23 March 2012. <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Nitrogen-volatilisation-losses-how-much-N-is-lost-when-applied-in-different-formulations-at-different-times>

³¹ R Brill, M Gardner, G McMullen (2012) Comparison of grain yield and grain protein concentration of commercial wheat varieties. GRDC Papers 10 April 2012, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Comparison-of-grain-yield-and-grain-protein-concentration-of-commercial-wheat-varieties>

More information

[Soil Quality Fact Sheet: Soil nitrogen supply](#)

in focus

5.8.6 Effectiveness of late nitrogen application

Results of a GRDC-funded Southern Farming Systems (SFS) trial indicate that by applying N at GS70, neither yield nor protein was increased. This was due to the plant beginning to senesce and being unable to utilise N.

Although it may be time saving to apply N upfront at sowing, this will result in a range of issues with canopy management, because upfront N will result in excess tillers. Therefore, there are benefits with a split application of N, for example, limited numbers of tillers, which may have better grainfill at the end of the season, especially when there is a dry finish.

However, there are risks associated with a split application. A wet season may prevent access to the paddock, resulting in an application that is later than ideal, or loss of application. Leaving N application too late may result in tiller mortality, stunted crops in waterlogged paddocks, and loss of green leaf.

Key messages:

- Apply N early (stem elongation) for yield and later (head emergence) for protein.
- Decisions on N should be made as the season unfolds because a good finish can make significant difference.
- Given the total amount of N applied to the crop and the soft finish during the trial, all treatments met Australian Premium White (APW) specification for protein (>10.5%).
- There was no significant difference in yield or protein between the different urea treatments: urea–ammonium nitrate (UAN) and liquid urea.
- There was no significant difference between the 25 and 50 kg N/ha rates for yield; however, protein was increased at the higher rate.

Improving the efficiency of N usage is a challenge that farmers are facing worldwide; it is a crucial factor affecting the yield and protein levels of cereals.

Too much N may increase the susceptibility of the crop to disease pressures and inefficient water use through the production of excess canopy. However, too little N applied to a crop results in stunted yields, lower or limited protein levels and a decline in profitability. This relationship is shown in Figure 11 below.³²

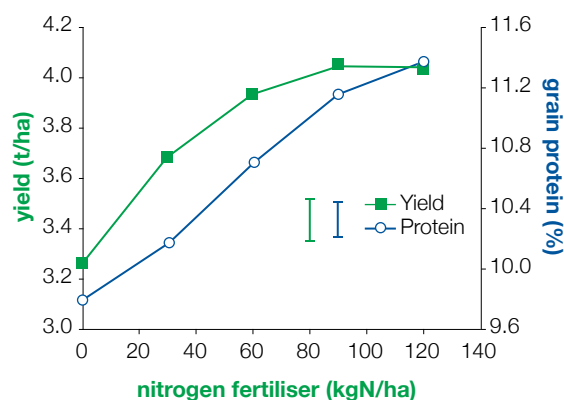


Figure 11: Grain yield (t/ha) and protein concentration (%) from 10 wheat varieties with varying rates of applied nitrogen (Brill et al. 2012).

³² B Cameron. Late nitrogen in wheat: better late than never? How late is too late. Southern Farming Systems, http://www.sfs.org.au/trial-result-pdfs/Trial_Results_2013/2013_LateNitrogenInWheatBetterLateThanNeverHowLateIsTooLate_VIC.pdf

5.9 Phosphorus

Australian soils are characteristically low in P in their native state, with the exception of a few soils of basaltic origin and some alluvial soils. Agriculture can further deplete soil fertility, even in soils that are initially high in P.

Most of the P in soils is associated with organic matter. Even in mineral soils, 20–80% of the total P will be present as organic forms.

Adequate P is essential for the early growth of wheat. Many Victorian soils are low in available P, and much of the crop requirement may need to be supplied through the application of fertilisers at sowing time. Paddock history of P application and crop yields in conjunction with soil test results and economics of application will determine the rates required.

The rule of thumb is a requirement for 3 kg/ha of available P for each tonne of wheat anticipated. The application is then adjusted in the light of soil test results.³³

In most cropping systems, the Colwell-P soil test is still the benchmark soil P test used in Australia. Critical values differ between soil types, and the values given in [Table 2](#) above are expressed for the major soil types in south-eastern Australia.

Through the GRDC-funded Better Fertiliser Decision for Crop Nutrition (BFDC) project, the results of >5000 Australian crop nutrition trials have been collated in a single database. Of these, >2200 trials are from south-eastern Australia.

The PBI could not be directly related to the critical soil test value using the [BFDC Interrogator](#), although other published data indicate that critical Colwell-P increases with PBI. Note that most of the trials were conducted prior to the PBI test being available.

Soil critical-P test value is not affected by wheat yield except where yields are very low (<1 t/ha).

On highly calcareous soils (Calcarosols), the DGT-P soil test provides a better prediction of crop response to fertiliser than Colwell-P.³⁴

5.9.1 Phosphorus deficiency

Description (Figures 12 and 13):

- Early growth and vigour are reduced, with spindly plants under severe deficiency.
- All leaves are dull dark green.
- Slight mottling is visible on oldest leaf and tip begins to yellow.
- Yellow area moves down the leaf, with the base remaining dark green (no 'arrow', so not like K deficiency).
- Yellow areas die quite quickly, with the tip becoming orange to dark brown and shrivelling, with the remainder of the leaf turning yellow.³⁵

Phosphorus deficiency is one of the most widespread of nutrient deficiencies. Phosphorus is an important component of many molecules in plant cells; therefore, it is important for growing tissue where cells are actively dividing (e.g. development of seedling roots, flowering and the formation of seed). Phosphorus-deficient plants are stunted, dark green plants with short, erect leaves and stout stems that often develop orange, red or purplish discoloration. Many soils in wheat-growing areas will respond to the application of phosphate fertilisers.

³³ Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

³⁴ GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, <http://www.grdc.com.au/GRDC-FS-SoilTestingS>

³⁵ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

More information

[GRDC Fact Sheets: Phosphorus management \(Southern Region\)](#)

[GRDC Update Papers: Phosphorus— are we going to hit the wall and how much P in 2015?](#)

[GRDC Update Papers: Subsoil manuring](#)

[BFDC Interrogator: Case study: phosphorus in wheat](#)

Phosphorus deficiency is more likely to occur after a long fallow due to low numbers of arbuscular mycorrhizal fungi (AMF) in the soil. These AMF are the beneficial soil fungi that help plant roots take up both P and Zn.³⁶



Figure 12: Adequate (left) and inadequate (right) phosphorus nutrition. (Photos: Nigel Wilhelm, SARDI)³⁷



Figure 13: Phosphorus deficiency on the right-hand side of the image. (Photo: Nigel Wilhelm, SARDI)

³⁶ DAF Qld (2010) Other elements of crop nutrition—phosphorus. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/other-nutrition>

³⁷ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

Similar symptoms

Nitrogen deficiency also has yellowing of the oldest leaves, but death of the yellow tissue occurs more rapidly than with N deficiency.

Contributing factors

Low available soil P and/or low AMF.³⁸

5.9.2 Crop demand for phosphorus

Crop demand for P can be considered in two distinct phases: during early development (from emergence to the end of tillering, but before stem elongation), and then during the growth and grain-filling period.

During early development, the requirement for P is small (perhaps 1 kg P/ha), but the root system is small and inefficient, so the crop responds to a concentrated P source close to the seed and developing roots. Ensuring that these young plants have adequate P is essential to determination of grain number (i.e. yield potential) and ensuring vigorous seedling development (Table 3). Hence, it is important to apply 'starter fertilisers' with the seed, so that the seed has a ready source of P for its development.

Subsequent P requirement is much larger, and largely mirrors the accumulation of crop biomass. As a rule, crops require ~5 kg P accumulated to produce 1 t of grain yield, so a typical crop of 3 t/ha will take up ~15 kg P/ha. Only 1–2 kg will be taken up from the banded P fertiliser applied at planting (either in or below and beside the seeding row). The rest comes from the soil profile, with about half coming from the top 10–15 cm and the rest from the next 15–30 cm. These proportions will change with seasonal conditions—root activity in surface layers will be minimal in dry periods. Having plant-available P in the immediate subsoil (i.e. 10–30 cm preferably) becomes a critical factor for crop performance.

The need for P fertiliser can be determined by using soil tests (0–10 and 10–30 cm) and/or test strips of fertiliser.³⁹

Table 3: Adequate soil phosphorus ranges (Colwell-P) for different soil types

Soil test reading	Soil type
20–30 mg/kg	Sand
25–35 mg/kg	Loam
30–40 mg/kg	Clay

5.9.3 Phosphorus availability

A key consideration for growers with regard to fertiliser management is how much P the stubble will supply, and when this P will be available to plants during the growing season. Many studies suggest that the timing and quantities of P release vary and that they are not well explained by the total amount of P or the carbon (C):P ratio in the residues.

Stubble type, size and placement, and moisture supply and amount can all significantly influence the timing and amount of P released from stubbles to the soil. Recent research aims to improve identification of P forms in crop stubble and to understand how these forms influence P release and breakdown from stubble, thereby providing a better estimation of the contribution of stubble P to subsequent crop P uptake.

More information

[GRDC Fact Sheets: Soil testing for crop nutrition \(Southern Region\)](#)

³⁸ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

³⁹ DAF Qld (2010) Other elements of crop nutrition—phosphorus. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/other-nutrition>

Phosphorus within the stubble can be released directly to soil as soluble P (where it can be used immediately by the crop or chemically fixed onto the soil) or can be absorbed by microorganisms and subsequently released back into the soil.

The chemical composition of crop stubble plays an important role in the rate of nutrient release. The quality of crop stubble is usually assessed by using its C:N:P ratio, because this ratio influences the proportion of P that follows pathways of immediate release or incorporation by microorganisms and subsequent release back to the soil.

This occurs because the microbial population requires a C source for energy, which is provided by the stubble, as well as certain amounts of nutrients such as N and P to continue to grow. How crop stubble affects soil P availability will therefore depend on the balance between direct release of P (and C and N) from stubble and microbial uptake and release. The presence of different chemical P forms in the stubble is likely to influence the proportion of P that undergoes direct release or microbial uptake and decomposition.

Research results indicate that P release is strongly controlled by the size of the stubble pieces, and studies that use ground stubbles are likely to over-predict the rate at which P is released from stubble in the field.⁴⁰

5.9.4 Long-fallow disorder

When fallow length exceeds 12 months through crop rotation or drought, moderate to high rates of P fertiliser are often required to prevent long-fallow disorder affecting the crop. A suggested rate is 10 kg P/ha. Wheat following canola may also benefit from higher P rates because canola is not a host of AMF. For more information, see [GrowNotes Wheat South Section 1. Planning and paddock preparation](#).

5.9.5 Reduced tillage

Reduced tillage or no-tillage may accentuate the responsiveness of a soil to phosphate fertiliser. This is due to the immobilisation of phosphate in the soil surface. Phosphorus is immobile in the soil—unlike nitrate-N, it does not move in soil water. Phosphate fertilisers are most effective when applied at planting in direct contact with, or just below, the seed. Table 4 shows the actual rate of fertiliser product required to apply various rates of P.

Table 4: Products used primarily to supply phosphorus

Product trade name	% P in product	Required rate of application of P (kg/ha)				
		4	6	8	10	15
Mono-ammonium phosphate (MAP)	22	18	27	36	45	68
Di-ammonium phosphate (DAP)	20	20	30	40	50	75
CK 700® (8.3% P)	8.2	49	73	98	122	183
Granulock® Z (21.8% P)	20.5	20	24	39	49	73

5.9.6 Phosphorus budgeting

The traditional practice of banding P below or with the seed seeks to provide a rapid boost to root growth, promoting vigorous root systems, which can then set the plant up for a good season and good yields. How much P is required to achieve vigorous roots? To answer this question, we need to understand what is going on below the surface. How does a root system change the way that it grows in response to a high-concentration patch of P?

Figure 14 shows wheat roots responding to a band of P placed evenly distributed (between the blue dots) in a column ~0.3 m long and, by contrast, the root response to a granule of P placed at a similar depth in a similar pot.

⁴⁰ S Noack, M McLaughlin, R Smernik, T McBeath, R Armstrong (2012) The value of phosphorus in crop stubble. GRDC Update Papers, 23 February 2012

These technologies allow researchers to answer questions about how root architecture changes in response to nutrition. The research can answer the question of how much P is required to create an architecture that allows for extensive exploration of soil volume. The aim is to find the lowest amount of P (and N) required to stimulate an efficient root system, which then frees the P resource to be spread more widely in the surface and subsoil, where those newly foraging and stimulated roots are best placed to find and exploit it in moist soil.⁴¹

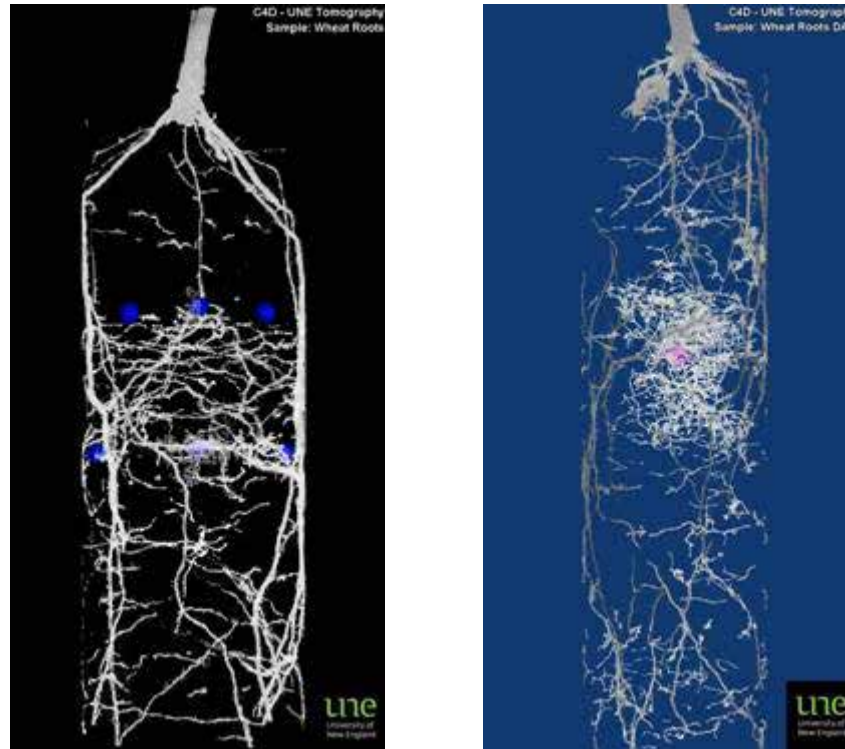


Figure 14: 3D Computer-aided tomographs of cereal root systems supplied with P in a diffuse band (left panel) or in a granule (right panel) after 30 days of growth.

5.9.7 Forms of phosphorus

Adequate P is not only an essential component of profitable and sustainable crop production but is also an increasing component of crop gross margins. The price of phosphatic fertilisers has increased, leading to interest in ways to improve P-fertiliser-use efficiency.

Use of liquid fertilisers has increased considerably, especially for the supply of N for crop production. Several products are available from a range of suppliers for use as starter fertiliser to provide P and micronutrients. Research in South Australia on highly calcareous soils (20–90% CaCO₃) has shown possible benefits of using liquid fertilisers over the traditional granular forms.⁴²

Soils in northern NSW have CaCO₃ concentrations much less than those found in the calcareous soils of South Australia. Researchers reported on dry matter responses to liquid and granular P fertilisers from soils collected from around Australia. Six soils from the northern grains region were studied, with CaCO₃ levels ranging from undetectable to 1.3%. Five of these soils had positive dry matter responses to liquids, which was greater than when granular products were used.

⁴¹ C Guppy, R Flavel (2011) Cereals seeking phosphorus: How much to spend on a first date? GRDC Update Papers, 6 Sept. 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Cereals-seeking-phosphorus-How-much-to-spend-on-a-first-date>

⁴² B Manning, J Hunt, G McMullen (2012) Phosphorus fertiliser—Does product choice matter? Northern Grains Region Trial Results Autumn 2012, pp. 83–86. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/430291/Northern-grains-region-trial-results-autumn-2012.pdf

One of the key conclusions was that grain yield responses to liquid P need to be assessed under field conditions. The aim of these trials was to determine whether there is any benefit in using liquid instead of solid P, and whether the volume of water used to apply liquid P has an influence on yield by increasing the volume of soil in which the P is distributed at higher volumes of water. Because most P is applied as starter fertiliser containing Zn, treatments plus and minus Zn were also included.

Grain yield responses to fertiliser P were not as clear as was expected from this site. The wet seasonal conditions may have influenced the P response, with increased root growth resulting in a greater capacity of the crop to utilise existing soil P reserves.

There was no difference between the types of fertiliser used with respect to plant growth or grain yield. When deciding whether to use liquid P fertilisers, the additional cost of equipment to use these fertilisers also needs to be taken into account.⁴³

On most soils, although liquid P might initially increase dry matter production, it offers no agronomic advantage or yield increase over granular P. If in doubt about the usefulness of any new products, use test strips on-farm and assess economic (as well as agronomic) effectiveness before adopting, or refer to local trial data.

Manures

Manure might seem cheaper by the tonne, but available nutrients are released very slowly (only 50% of P is available in the first year); therefore, larger quantities are needed to supply enough nutrients for plants to use in the first year.

When using manures, always ensure that the manure being applied is analysed for available nutrients, because the nutrient content varies greatly depending on source and storage.

The cost of transporting and applying manure may be greater than of traditional fertiliser, and should be added to budget comparisons.⁴⁴

5.10 Sulfur

Historically, S has been adequate for crop growth because S is supplied in superphosphate and in rainfall in coastal areas, and some S comes from gypsum. In the Southern Region, S-responsive soils are uncommon in cereals, but can be seen in canola.

Sulfur inputs to cropping systems have declined with the use of triple superphosphate (TSP) and mono- and di-ammonium phosphate (MAP and DAP), which are low in S. Sulfur is also subject to leaching and in wet seasons may move beyond the root-zone. Occurrence of S deficiency appears to be a complex interaction between the mineralisation of S from soil organic matter, seasonal conditions, crop species and plant availability of subsoil S. Similar to N, these factors affect the ability of the soil-S test to predict plant-available S.

Interrogation of wheat trial data in the BFDC database found that the critical soil-S test value (measured in the 0–10 cm soil layer) is poorly defined when considered across all soil types.⁴⁵

⁴³ B Manning, J Hunt, G McMullen (2012) Phosphorus fertiliser—Does product choice matter? Northern Grains Region Trial Results Autumn 2012, pp. 83–86. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/430291/Northern-grains-region-trial-results-autumn-2012.pdf

⁴⁴ GRDC (2009) Profitable nutrient use starts with knowing the reserve. Targeted Nutrition at Sowing Fact Sheet, GRDC, 2009, <http://www.grdc.com.au/Resources/Bookshop/2010/10/-/media/27AA21276EE7425FA368BE48A95B5676.pdf>

⁴⁵ GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, <http://www.grdc.com.au/GRDC-FS-SoilTestingS>

5.10.1 Deficiency symptoms

Description (Figures 15 and 16):

- Young plants are pale green or yellow with only limited stunting.
- Upper leaves of mature plants are pale green to yellow, with the lower leaves remaining green (unlike N deficiency).
- Tiller production is not affected, although mature tillers will produce small heads.
- Whole plant is pale green with a greater yellowing in the newest leaves, which are a 'butter' yellow.
- Whole leaves are light yellow with no stripes or green veins.
- With severe deficiency, leaf tips of old leaves can die.

In severe deficiencies, the upper leaves are yellow to white in colour, with the lower leaves turning pale green. Tiller number will also be reduced.

Testing to 60 cm is suggested, with soil test levels <4 mg S/kg indicative of areas where it is necessary to undertake test strips of S application for growth responses. Consider applying ammonium sulfate into the soil at 75–100 kg/ha (15–24 kg S/ha) or broadcasting gypsum (calcium sulfate) at the rate of 500 kg/ha as test strips.⁴⁶

Similar symptoms

Nitrogen deficiency symptoms are similar, with yellowing, but N deficiency occurs in the oldest leaves first rather than the whole plant.

Contributing factors

Low soil fertility (organic matter) and cold wet conditions reduce mineralisation and uptake of S. Acid sandy soils are subject to leaching of S. Fertilisers such as DAP and MAP are low in S.⁴⁷



Figure 15: Sulfur-deficient plants (first three from left) compared with a plant receiving adequate S nutrition. (Photo: J Yeates, DAFWA)

⁴⁶ DAF Qld (2012) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

⁴⁷ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>



Figure 16: Sulfur-deficient wheat crop. (Photo: Matthew Whitney, Dodgshun Medlin Ag Management)

5.11 Potassium

Potassium (K) is important in vegetative growth and is essential for a number of metabolic processes, yet its precise functions are poorly understood. It does enhance N uptake and can increase protein content. It can also help to prevent lodging in cereals.

With the gradual decline in soil K levels from crop removal and historically low fertiliser application rates, some situations (particularly red soils) require K fertiliser applications. However, crops also vary in their response to improved soil K levels. Generally, winter cereal responses are low to moderate unless gross deficiencies occur.⁴⁸

Generally, in the Southern Region, cropping soils are unresponsive to additions of K. However, as crops continue to mine K from soils, this may change in the future. Potassium deficiency is more likely to occur on light soils and with high rainfall, especially where hay is cut and removed regularly.

Factors such as soil acidity, soil compaction and waterlogging will modify root growth and the ability of crops to extract subsoil K.

The critical values for Colwell-K in wheat vary with soil type from ~40 mg/kg on Chromosols, to ~49 mg/kg on Kandosols and ~64 mg/kg on Brown Ferrosols.

There was some evidence in the BFDC analysis that critical values increased with increasing crop yield and on soils with no acidity constraints to root growth.⁴⁹

Potassium fertiliser inputs in Australian cropping systems have generally been low relative to other nutrients, with Reuter *et al.* (1997) estimating that, nationally, Australia had a negative K balance, with that balance strongly negative in broadacre cropping regions.⁵⁰

⁴⁸ DAF Qld (2102) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

⁴⁹ GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, <http://www.grdc.com.au/GRDC-FS-SoilTestingS>

⁵⁰ D Reuter D, D Duncombe-Wall, G Judson G (1997) Potassium balance in Australia's broadacre industries: a contemporary national and regional analysis. In Proceedings of the First Workshop on Potassium in Australian Agriculture. pp. 1–8. UWA Press.

5.11.1 Deficiency symptoms

- Young plants grow very slowly and they are often stunted.
- In older plants, the lower leaves exhibit a marginal 'scorch', with yellow to brown margins towards the leaf tips.
- Potassium-deficient plants may also lodge more readily.⁵¹
- The whole plant has reduced vigour and spindly growth.
- Specific symptoms first appear on the oldest leaves, which are speckled along their whole length, quickly spreading to the tip and margins in severe cases.
- As leaves die back from the tip and margins, a spear-shaped pattern of green remains (clearest characteristic).
- Old leaves often die completely and plants appear to hay-off prematurely.

Figure 17 shows the degree of deficiency from adequate, yellow mottling, death of leaf tips and the green-spear effect.

Similar symptoms

Nitrogen deficiency also shows yellowing of oldest leaves, but leaf death occurs much more rapidly with K deficiency.

Boron toxicity is similar, although symptoms usually occur later in crop development than K deficiency.

Contributing factors

Sandy soils with leaching potential can contribute to K deficiency. A history of high removal of hay and/or grain will deplete K.⁵²



Figure 17: The leaf on the left shows adequate potassium nutrition; the others show inadequate K. (Photo: Noel Grundon, QDPI)⁵³

⁵¹ DAF Qld (2102) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

⁵² GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

⁵³ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

5.11.2 Critical levels and inputs

Potassium soil tests are reported as exchangeable K (meq/100 g or cmol/kg) or, in the case of a Colwell-K test, as mg available/kg. Research is under way to improve definition of critical soil-test K levels, but in the interim, exchangeable K <0.3–0.4 cmol/kg or 130–160 mg Colwell-K/kg would be considered low–marginal, and test strips worth a try.

Remember that, like P, K is effectively immobile in the soil, so profiles are tending to stratify, with much higher levels in the top 10 cm and significant depletion in the 10–30 cm layer. Testing for soil K in both the 0–10 and 10–30 cm layers is advisable, with the deeper K essential when the topsoil is dry.

Potassium fertilisers can be side-banded at planting, drilled in pre-plant, or broadcast and cultivated in fallow or even prior to a preceding crop. The residual value of K fertiliser is excellent, so sporadic applications at higher rates can be an effective alternative to lower rates with each crop. However, K banded in the seed row can affect germination.

Once K fertility of the surface layers has been restored, deep application is the best way to apply K fertilisers to maintain soil productivity. A proportion of the deep K taken up by the crop is returned to the soil surface in the litter and crop stubble, which replenishes the K fertility of these surface layers.

Although soil K reserves are greatest in heavier alluvial and cracking clay soils, it is important to maintain adequate K soil levels by replacing that removed in harvested product as often as possible. Once soil K levels have been depleted in these soils, very heavy fertiliser K applications are required and this becomes prohibitively expensive.⁵⁴

Field studies have examined crop yield–soil-test K relationships for a Ferrosol, and glasshouse studies have been used to determine patterns of K accumulation in Ferrosols with different K status.

Crops varied markedly in critical soil-test K for grain yield, but there was no significant response to K placement in either grain or cotton-seed yield. Patterns of K accumulation differed between crop species. Although all crops exhibited faster relative accumulation of K than of biomass, relative K accumulation rates in maize were much greater than in wheat or sorghum. This was related to the more indeterminate growth habit of wheat and sorghum resulting from addition of tillers compared with maize. Delayed access to surface-applied K until flowering in all species resulted in significant late-crop K uptake but no significant biomass or grain yield responses, even under conditions of severe K deficiency.⁵⁵

More information

[BFDC Interrogator: Case study: potassium in wheat](#)

5.12 Micronutrient deficiencies

Micronutrient deficiencies can be difficult to diagnose and treat. However, by knowing your soil type, considering crop requirements and the season, and supporting this knowledge with diagnostic tools and strategies, effective management is possible.

Key points:

- Micronutrient deficiencies are best determined by looking at the overall situation: region, soil type, season, crop, and past fertiliser management.
- Soil type is useful in determining the risk of micronutrient deficiencies.
- Soil testing can be a useful indicator.
- Tissue testing is an accurate way to diagnose a suspected micronutrient deficiency.
- When tissue testing, the appropriate tissues should be sampled at the right time. Plant nutrient status varies according to plant age, variety and weather conditions.

⁵⁴ DAF Qld (2102) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

⁵⁵ RF Brennan, MJ Bell (2013) Soil potassium–crop response calibration relationships and criteria for field crops grown in Australia. *Crop and Pasture Science* 64, 514–522, <http://www.publish.csiro.au/paper/CP13006.htm>

- The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small.
- When applying fertiliser to treat a suspected deficiency, leave a strip untreated. Either a visual response or tissue testing can allow you to confirm whether the micronutrient was limiting.⁵⁶

5.12.1 Zinc

Zinc is essential for protein shape and consequently important for enzyme function in many different tissues.

Deficiency symptoms appear as oily grey-green patches in the centre of leaves. Young leaves are most affected. Deficiency is typically associated with alkaline soils over a wide range of textures. Lime and gypsum can reduce Zn availability.

Critical tissue concentrations in the youngest expanded blade of wheat are 8–10 mg/kg but the response curve is very steep. Zinc supplements can be applied with fertiliser as zinc oxide, chelated Zn or zinc sulfate. The last two products are soluble and can be used for foliar applications. Product efficacy varies with the time and placement of application.⁵⁷

Deficiency description (Figures 18 and 19):

- Plants are stunted with short, thin stems and usually pale green leaves.
- Young to middle leaves develop yellow patches between the mid vein and the edge of the leaf, extending lengthways towards the tip and base of the leaf.
- These areas eventually die turning pale grey or brown.
- Plants take on a water-or diesel-soaked appearance.
- Affected areas may remain separate or join, with the death of the entire central leaf area; tip, base and margins remain green.
- With severe deficiency, yellow areas and grey-brown lesions develop on the leaf sheath; reduced tillering with no or little grain produced.
- Maturity is delayed. Mature plants are a dull grey colour compared with a bright yellow appearance of a healthy crop.

Similar symptoms

The fungal disease yellow leaf spot has similar symptoms.

Contributing factors

Application of some herbicides makes the problem worse. Zinc deficiency occurs on many soil types but is most severe on highly alkaline clay soils and very infertile siliceous sands, yellow gravelly sands, yellow earths, highly alkaline peat soils and highly alkaline coastal sands.⁵⁸

⁵⁶ GRDC (2013) Micronutrients. Crop Nutrition Fact Sheet GRDC, 4 November 2013, <http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients>

⁵⁷ DAF Qld (2012) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

⁵⁸ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>



Figure 18: Zinc deficiency in wheat. (Photo: Matthew Witney, Dodgshun Medlin Ag Management)



Figure 19: Zinc deficiency symptoms on wheat leaf. (Photo: Matthew Witney, Dodgshun Medlin Ag Management)

5.12.2 Copper

Copper is essential for chlorophyll formation and pollen production as well as baking quality. Wheat and barley are more responsive to Cu than are lucerne and canola.

Deficiency is common in organic soils and sandy soils that are low in organic matter, as well as where there is high iron (Fe), manganese (Mn) or Al in the soil. Critical tissue levels have been reported as <1.5 mg/kg at the youngest expanded blade in wheat.⁵⁹

Deficiency symptoms in wheat include (Figures 20 and 21):

- wilting despite ample water supply
- leaf-tip dieback of youngest leaves with leaves becoming tightly twisted
- ear-tip dieback, where the top of the head turns white or yellow (the remainder of the head stays green, but may not set grain)
- white heads and delayed maturity, and melanism (blackening) of stems
- ear branching
- upper node tillering⁶⁰

Detailed description:

- Heads have 'rat-tail' appearance with full grain in the base, shrivelled grains in the middle and a withered dead tip. Gaps in heads can also be present due to unfertilised embryos amongst fertilised grains (Figures 22 and 23).
- With marginal deficiency, grain is shrivelled, with the stem and head bending over.
- Grain yield reduced due to reduced pollen fertility.
- Whole plants are light green and begin to wilt at early tillering despite adequate soil moisture.
- First characteristic symptoms are sudden death and withering (curling) of the tip and up to half the length of young leaves.
- Tips of young leaves hang down and turn yellow.
- Base of leaf can remain green until the crop ripens.
- Old leaves remain green and apparently healthy.
- With severe deficiency, new growth withers before unfolding; tillering is reduced, stems are weak.
- Length of stems is reduced, and stem, nodes and spikelet glumes can purple; tillering from base of upper leaves.
- Mature plants are a dull grey-black colour with white heads compared with bright yellow appearance of healthy crop.

Similar symptoms

Drought stress, frost, take-all and Mo deficiency have similar symptoms. Boron and Ca deficiency also cause shoots to wither.

Contributing factors

Intensive cropping rotations with grain legume crops can contribute to deficiency. Additional N fertiliser can exacerbate the severity of the deficiency (crop still appears N-deficient).⁶¹

⁵⁹ R Norton (2014) Trace elements: copper and manganese. GRDC Update Papers, 20 August 2014, <https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Trace-elements-copper-and-manganese-their-role-requirements-and-options>

⁶⁰ DAF Qld (2012) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

⁶¹ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>



Figure 20: Copper deficiency. (Photo: Doug Reuter, CSIRO)



Figure 21: Copper deficiency symptoms on wheat leaves. (Photo: Doug Reuter, CSIRO)



Figure 22: 'Rat-tail' appearance of heads with full grain in the base indicating copper deficiency. (Photo: Ross Brennan, DAFWA)



Figure 23: Deformed heads indicating copper deficiency. (Photo: Ross Brennan, DAFWA)

Alleviation

Copper can be applied as an additive to fertilisers, or as foliar spray as copper sulfate, copper oxychloride or chelated Cu. It also has a fungicidal effect.

Copper sulfate applied to the soil at 10–20 kg/ha prior to or at planting will last for a number of years. One foliar spraying at booting may still be necessary in dry years.

Alternatively, apply two foliar sprays of 1% copper sulfate/ha (1 kg copper sulfate to 100 L water/ha). Apply the first spray 3–5 weeks post-emergence and the second spray any

time from when the ear begins to swell the stem of the plant to when the plant is in the boot stage. Foliar sprays have little residual value and they must be applied every year.⁶²

5.12.3 Boron

Key points:

- Boron is essential for germination and sugar metabolism.
- Lucerne is more susceptible to deficiency than canola and wheat is less susceptible than canola.
- Symptoms of deficiency include stem splitting and poor seedset.
- Liming can induce boron deficiency.
- Critical tissue levels are <2 mg/kg in the youngest mature leaf blade at mid-late tillering. Leaching can reduce tissue levels.
- Boron sources are borax, boric acid, Solubor®, ulexite and sodium pentaborate.
- Even application is critical.

Description of deficiency:

- Newer leaves split along the leaf close to the midrib.
- Edges of young leaves have a saw-tooth effect (Figure 24).
- Severe deficiency causes increased tillering, new shoots look water-soaked and paler, and leaves are distorted along edges; finally, new growth dies and shoots wither.

Similar symptoms

Copper and Ca deficiency show similar symptoms of shoots withering.⁶³

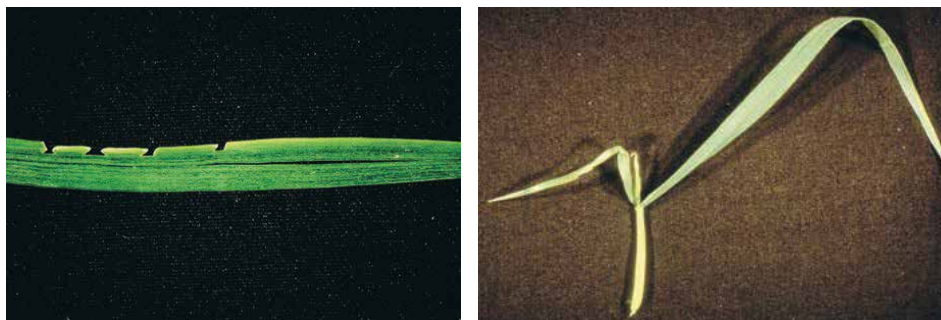


Figure 24: Deformed leaves indicating boron deficiency.

Boron toxicity

Boron is essential for plants, but in some soils, it accumulates to toxic levels. Symptoms are yellowing and death of leaf tips, starting on oldest leaves first (Figure 25). Symptoms often do not appear in early vegetative growth.

Similar symptoms

Nitrogen and K deficiency appear similar but these are most obvious early in crop development (before boron toxicity symptoms normally appear).

Contributing factors

Boron toxicity can occur with high boron levels in subsoil and when growing boron-intolerant varieties.⁶⁴

⁶² DAF Qld (2012) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

⁶³ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

⁶⁴ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

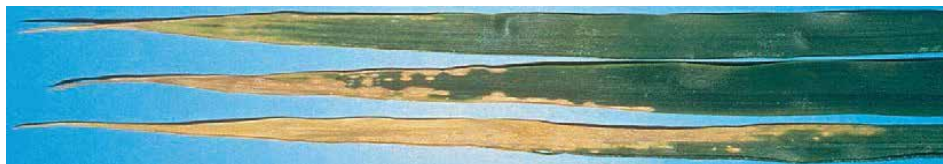


Figure 25: Symptoms of boron toxicity. (Photo: Brian Cartwright, CSIRO)

5.12.4 Iron

Key points:

- Iron is an essential component of chlorophyll and respiratory enzymes.
- Legumes are more responsive to Fe than are cereals.
- Chlorosis of the youngest part of the plant is the most common symptom of deficiency.
- Deficiency is worst in high-pH and low-organic-matter soils, especially if there is a lot of free bicarbonate (of soil or irrigation water origin).
- Soil analysis is not able to provide critical values, and tissue samples can be easily contaminated with Fe from soil. Levels >70 mg/kg in tissue seem adequate.
- Foliar sprays are useful as iron sulfate or side dressings with iron chelates.

Description of deficiency:

- New leaves have striping, with alternate yellow and green stripes down the length of the leaf (Figures 26 and 27).
- Under severe Fe deficiency, new growth may turn white.
- New growth remains yellow for some time before the leaf begins to die.

Similar symptoms

Magnesium deficiency usually has a 'bead' appearance, and Mn deficiency causes yellow striping of new growth but the striping is not as pronounced.

Contributing factors

Contributing factors include highly calcareous soils, cold and wet conditions, and application of high rates of lime.⁶⁵



Figure 26: Iron deficiency on wheat leaves. (Photo: Hungry Crops, QDPI)

⁶⁵ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>



Figure 27: Iron deficiency in wheat crop. (Photo. Mark Seeliger, PIRSA)

5.12.5 Manganese

Key points:

- Manganese is a common enzyme cofactor for chlorophyll and photosynthesis.
- Deficiency symptoms are often preceded by wilting and then chlorosis of younger leaves, often at the base of the leaf.
- Deficiency is mainly a problem on soils with high organic matter, and those with free lime present. It may be toxic at low pH (<5).
- For cereals, tissue concentrations of <12 mg Mn/kg in the youngest mature leaf are considered deficient.
- Foliar Mn can be more efficient than soil-applied Mn, because the latter can result in Fe or phosphate precipitates. Chelated formulations are also available.

Description of deficiency:

- It often appears as patches of pale, floppy wheat in an otherwise green, healthy crop (Figure 28).
- New leaves are pale compared with old leaves and appear limp, with some withering of new shoots.
- Pale green–yellow striping appears at the base of the youngest fully opened leaf.
- As leaves develop, the striping becomes more pronounced, particularly in the middle of the leaf where patches begin to die and the leaf collapses (Figure 29).
- By this stage, the leaves are usually located on the middle of the plant.
- Maturity is delayed.



Figure 28: Manganese deficiency in wheat crop.



Figure 29: Manganese deficiency symptoms on wheat leaf. (Photo: Nigel Wilhelm, SARDI)

Similar symptoms

Iron deficiency causes striping but is more even and more vivid with no flecking.

Contributing factors

Manganese is low in many acid soils and is lost from free-draining soils (e.g. sandy soils). Highly calcareous sands, very infertile siliceous sands, alkaline peats, cold and wet conditions, and high rates of lime are contributing factors to Mn deficiency. Application of some herbicides makes the problem worse.⁶⁶

Manganese toxicity

Manganese toxicity symptoms include grey flecks or either yellow or brown spots developing on leaves (Figure 30).

Similar symptoms

The flecking symptom could be confused with insect damage, and the yellow spots could be confused with some leaf diseases or herbicide damage.

Contributing factors

Toxicity is likely to occur in acid soils ($\text{pHCaCl}_2 < 4.5$) and in wet, poorly drained soils; these conditions make Mn more available for plant uptake.⁶⁷

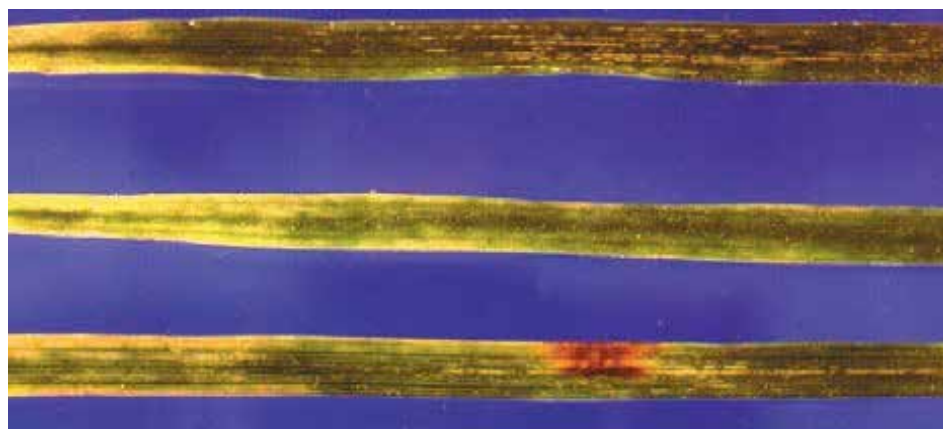


Figure 30: Manganese toxicity. (Photo: Brendan Scott, Agriculture NSW)

5.12.6 Molybdenum

Key points:

- Molybdenum is important for nitrate reductase activity in all plants.
- Deficiency symptoms are similar to those of N deficiency.
- Availability increases with high soil pH, and deficiencies are common on acid soils, especially in high-rainfall areas.
- Tissue levels of 0.28–0.55 mg Mo/kg in the youngest mature leaf are adequate for canola, and <0.1 mg/kg at mid–late tillering in wheat is considered deficient.
- Very small quantities (50 g/ha) applied with fertiliser are usually sufficient, usually in the form of molybdenum trioxide. Sodium or ammonium molybdate can be used as sprays.⁶⁸

⁶⁶ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

⁶⁷ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

⁶⁸ Incitec Pivot. Molybdenum fact sheet. Fertfacts. Incitec Pivot, <http://www.incitecpivotfertilisers.com.au/en/Agronomy/-/media/Files/IPF%20Migration/FertFacts/MolybdenumFS/MolybdenumFSV3IPLLM15102009.ashx>



Figure 31: Wheat grown without (left) and with molybdenum. (Photo: Snowball and Robson 1988)

Description of deficiency (Figure 31):

- Symptoms are difficult to detect in the field, particularly early in the season.
- At low levels of N, the crops are pale with some limpness.
- As N levels increase, symptoms become more specific with all but the oldest leaves pale green with adequate to high levels of N.
- Middle leaves have a speckled flecking or yellow stripes.
- Leaves appear limp and water-stressed.
- Tip scorching of old leaves apparent at high N levels.
- Severe deficiency causes delayed maturity and empty heads.

Similar symptoms

Copper deficiency can cause wilting, delayed maturity and empty heads. Crimping on flag leaf is often confused as a symptom of Mo deficiency, but is usually a physiological effect.

Contributing factors

Factors include acidic soils, moderate to high levels of available soil N, and soils high in iron and aluminium oxides.⁶⁹

5.12.7 Magnesium

Description of deficiency (Figure 32):

- Plants appear unthrifty and water-stressed.
- New wheat leaves are pale and will soon yellow, remaining unopened with a twisted appearance.
- Yellowing becomes mottled (spots or beads) and finally the leaves die, but remain upright.
- Oldest leaves also become a mottled yellow and in some cases reddish along the leaf margins.
- With severe deficiency, the entire length of the leaf will remain folded or rolled.

⁶⁹ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

Similar symptoms

Potassium deficiency symptoms also include unthrifty and water-stressed plants, but yellowing and death only occur on the older leaves.

Contributing factors

Applications of high rates of high-quality lime can contribute. Magnesium deficiency is rare in broadacre agricultural crops.⁷⁰



Figure 32: Magnesium deficiency symptoms. (Photos: Brendan Scott, Agriculture NSW)

⁷⁰ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>