



SOUTHERN

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GRDC™ GROWNOTES™



GRDC™

GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

BARLEY

SECTION 5

NUTRITION AND FERTILISER

ORGANIC MATTER | 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 | CURRENT GENERAL IN-CROP NUTRITIONAL
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MICRONUTRIENT DEFICIENCIES

SECTION 5

Nutrition and fertiliser

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

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[GRDC Update Papers: Current nutrition issues in the cropping zone of Southern Australia](#)

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

[NSW DPI: BFDC Interrogator](#)

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[GRDC Update Papers: Soil organic matter—what is it worth to grain production and what practices encourage it](#)

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). Sulfur (S), copper (Cu), manganese (Mn) molybdenum (Mo) may be also be lacking in some soil types and growing areas.¹

Historically, rates of fertiliser application to barley crops have been low. Barley was perceived to perform well on poor soils and in low-fertility situations. This is not the case; in fertile soils, barley yields are comparable to those of wheat without necessarily producing a protein level above that acceptable for malting specifications.²

Management of N availability is vital to achieving optimal yields and quality in your barley crop. Unlike wheat, which attracts premiums for high protein, malting barley can attract a premium if protein falls 9–12%. A protein target of 12% will also maximise a barley crop's yield potential.³

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.⁴

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

5.1 Organic matter

Organic matter has a fundamental role in soils. It helps to ameliorate or buffer the harmful effects of plant pathogens and chemical toxicities. It enhances surface and deeper soil structure, with positive effects for infiltration and exchange of water and gases, and for keeping the soil in place (i.e. reducing erosion). It improves soil water-holding capacity and, through its high cation-exchange capacity (CEC), prevents the leaching of essential cations such as calcium (Ca), magnesium (Mg), K and sodium (Na). Most importantly, it is a major repository for the cycling of nutrients and their delivery to crops and pastures.

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 N Fettell, P Bowden, T McNee, N Border (2010) Barley Growth & development, PROCROP. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

³ DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries , Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting>

⁴ M Blumenthal, I Fillery (2012) More profit from crop nutrition. GRDC Ground Cover Supplement 16 February 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>

5.2 Declining soil fertility

The natural fertility of cropped agricultural soils can decline over time. 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 (Figure 1).

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 pulses 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.⁵



Figure 1: The natural fertility of cropped agricultural soils can decline over time.

5.3 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 fertiliser test strips. This helps to build an understanding of which nutrients the crop removes at a range of yield and protein levels.

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>

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.⁶

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.⁷

More information

[GRDC Update Papers: Making variable rate application a success on your farm](#)

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

[GRDC Update Papers: Subsoil manuring](#)

5.3.1 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
- 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.⁸

5.4 Understanding soil pH

A soil pH in calcium chloride (CaCl₂) 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. Barley is generally sensitive to soil pHCa <5.0.

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.⁹

At low pH, beneficial elements such as Mo, P, Mg, S, K, Ca, and N become less available and others may become toxic (Figure 2). Maintain soil pH(CaCl₂) at 5.5–6.5 to achieve maximum P availability for cereals.¹⁰

Lime can be applied to increase low pH levels. 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.¹¹ See more in the GRDC Update Paper: [pH-mapping and variable rate lime—50,000 plus hectares of experience](#).

⁶ P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide>

⁷ 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>

⁸ 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>

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

¹⁰ 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

¹¹ 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>

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

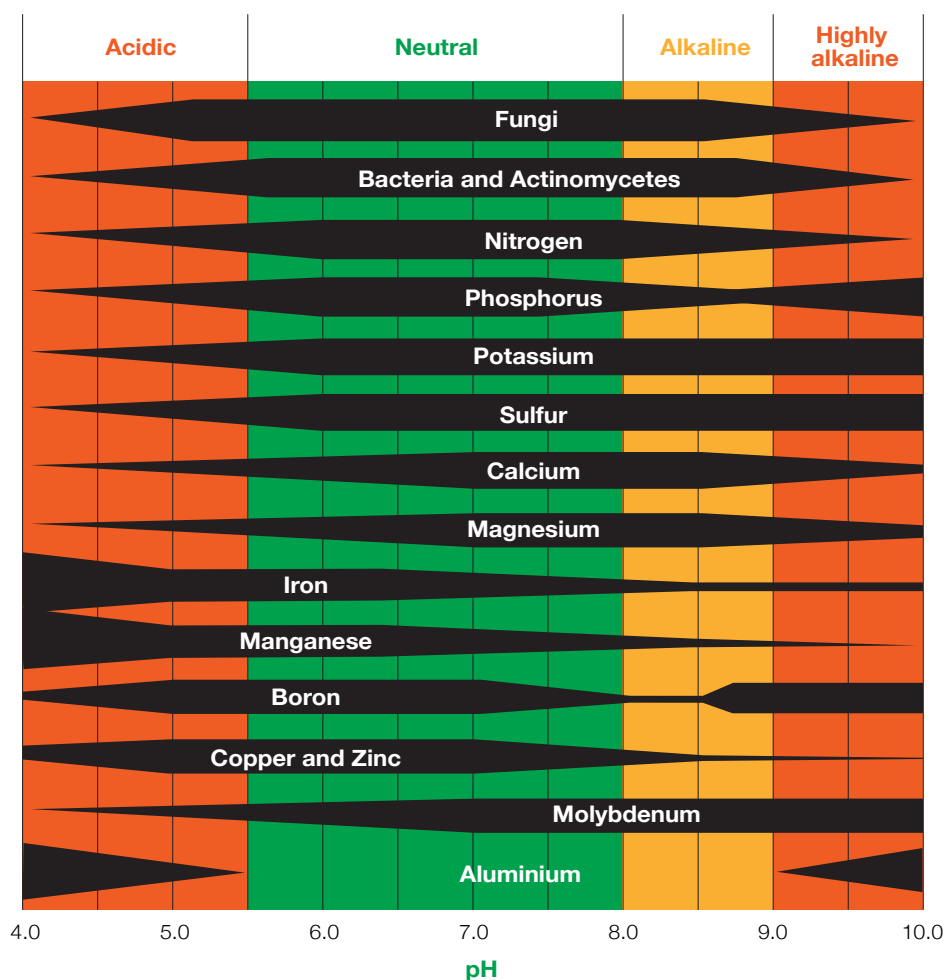


Figure 2: Availability of nutrients and other elements varies with soil pH.

5.4.1 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 $\text{pH}(\text{CaCl}_2)$.

5.4.2 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.¹²

¹² 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

5.5 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.¹³

Additive effects of N and P appear to account for most of the aboveground growth and yield response.¹⁴

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).¹⁵



Figure 3: Liebig's law of the minimum.

5.6 Crop removal rates

Ultimately, nutrients removed from paddocks will need to be replaced to sustain production. Table 1 shows amounts of nutrients removed by barley and wheat. 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 per tonne of grain and stubble for barley and wheat¹⁶

| | N | | P | | K | | S | |
|--------|-------|---------|-------|---------|-------|---------|-------|---------|
| | Grain | Stubble | Grain | Stubble | Grain | Stubble | Grain | Stubble |
| Barley | 20 | 7 | 2.5 | 0.7 | 4.5 | 18 | 1.5 | 1.5 |
| Wheat | 21 | 8 | 3 | 0.7 | 5 | 21 | 1.5 | 1.5 |

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 them.

¹³ 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>

¹⁴ 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>

¹⁵ Liebig's law of the minimum. Wikipedia, http://en.wikipedia.org/wiki/Liebig's_law_of_the_minimum

¹⁶ P Parker (2009) Nutrition and soil fertility. Canola Best Management Guide. GRDC, http://www.australianoilseeds.com/_data/assets/pdf_file/0011/8021/77_GRDC_Canola_Guide_Nutrition_and_soils.pdf

More information

Research paper:
[Assessment of sub-soil salinity and sodicity constraints to barley and faba bean production](#)

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 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.¹⁷

5.7 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.¹⁸

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, 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

More information

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

Soil test results are part of the information that supports decisions about fertiliser rate, timing and placement. However, to determine micronutrient status, plant tissue testing is usually more reliable.

5.7.1 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

¹⁷ 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>

¹⁸ 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>

For determination of 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.

Other measurements that aid the interpretation of soil nutrient tests include soil pH, percentage of gravel in the soil, soil organic matter content, P sorption capacity (currently measured as P buffering index, PBI), EC, chloride and exchangeable cations (CEC), including aluminium (Al).

5.7.2 Sampling depth and achieving representative samples

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 B (or other nutrient constraints) and moisture.

Sulfur testing at 0–10 cm is not as indicative of crop needs as 0–60 cm; 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. 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.

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).

5.7.3 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. 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.

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.¹⁹

¹⁹ 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>

Table 2: Critical values and critical ranges (mg/kg) of Colwell-P for the 0–10 cm sampling layer for 90% of relative yield²⁰

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 |
| | | Calcarosols | 34 | 26–44 |
| | Barley | Ferrosols | 76 | 46–130 |
| | Canola | All soils | 18 | 16–19 |
| | Field pea | All soils | 24 | 21–28 |

5.7.4 Fertiliser test strips

Test strips within the paddock 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 yield 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.

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 Q187002.²¹

5.7.5 Rules of thumb

Choose the same soil test package each year (including methods); otherwise, comparisons between years will be invalid. 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.

More information

[Agriculture Victoria: Using fertiliser test strips on pasture](#)

²⁰ 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>

²¹ 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](#)

For monitoring, sampling should 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](#).²²

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

5.7.6 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.²³ Test results are a good indication of N, but historical grain yield and protein levels from the paddock can also be used to assist N-requirement decision making.²⁴

Environmental conditions, including temperature, time and rainfall events can affect starting soil N; therefore, it is important to test later in summer and 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 than others to certain conditions.

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 product²⁵

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).

5.7.7 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 is used with the PBI to indicate the sufficiency and accessibility of P in the soil.

²² GRDC (2013) Better fertiliser decisions for crop nutrition. Crop Nutrition Fact Sheet, GRDC, 4 November 2013, <http://www.grdc.com.au/GRDC-FS-BFDCN>

²³ 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/Procrop-wheat-growth-and-development.pdf

²⁴ 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>

²⁵ 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>

More information

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

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

More information

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

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.

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.

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.²⁶

5.8 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.

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 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, levels of other nutrients, weather conditions, and stresses such as frost. The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small (Figure 4).

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.²⁷

²⁶ GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, January 2014, <https://www.grdc.com.au/~media/34D1397472234B6F8B195732A963F047.pdf>

²⁷ GRDC (2013) Micronutrients. Northern, Southern and Western Regions. Crop Nutrition Fact Sheet, GRDC, November 2013, <http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients>

More information

[GRDC Driving Agronomy Podcasts: Plant tissue testing—uncovering hidden hunger](#)

More information

[BCG: Barley and wheat disease management using foliar and fertiliser fungicides](#)

[BCG: Late nitrogen application to increase grain protein in barley](#)

[BCG: Management effects on barley varieties—row spacing, nitrogen and weed competition](#)

[GRDC Update Papers: Legume effects on soil N dynamics—comparisons of crop response to legume and fertiliser N](#)

[GRDC Update Papers: Management effects on barley varieties—nitrogen management and time of sowing](#)

[GRDC Update Papers: Nitrogen management—how much is enough and how much is too much](#)

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

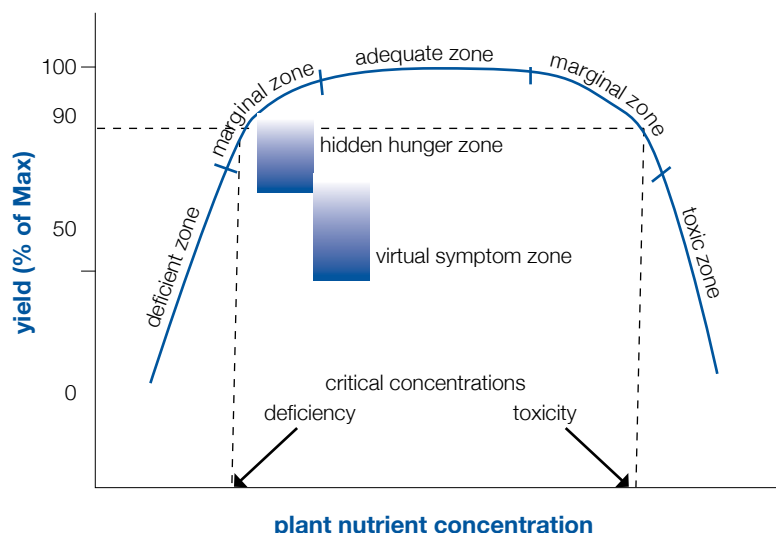


Figure 4: Generalised grain-yield response curve to plant nutrient concentration.

5.9 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.

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.²⁸

in focus

5.9.1 Southern Barley Agronomy Project and National Variety Trials

Agronomy trials were conducted in 2014 as part of the Southern Barley Agronomy Project, focusing on time of sowing, nitrogen rate and plant population decisions, with sites throughout southern New South Wales.

These trials showed the benefits to grain yield of targeting populations of 150 plants/m² across all rainfall zones. This will enhance the competitiveness of barley against weeds. Analysis of grain quality will determine whether there is a negative impact on receival standards. The combination of high plant population and high N inputs may lead to reduced yield in lower rainfall environments.

National Variety Trials were also conducted across the region. Three National Barley Trials were sown in 2014 at Gerobery, Condobolin and Parkes to determine the response of a core set of barley varieties to N rates and target plant populations across environments.

²⁸ GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, January 2014, <http://www.grdc.com.au/GRDC-FS-SoilTestingS>

Gerogery

This was the highest yielding of the trials. Compass^(b) achieved the highest yield in this trial (Table 3), showing that as well as being a reliable performer in the low-medium rainfall sites, it performs well in high-yielding situations. There was no response to N in this trial (high N background) but a general yield increase in all varieties as a result of increasing target plant population from 75 to 150 plants/m² and then to 300 plants/m² (Table 3). La Trobe^(b) did not perform as well (relative to other varieties) as it did in the low-medium rainfall sites.

Table 3: Effect of variety choice and plant population on grain yield (kg/ha) of barley at Gerogery in 2014

| Variety | Grain yield | Plants/m ² | Grain yield |
|----------------------------|-------------|-----------------------|-------------|
| Buloke ^(b) | 5392 | 75 | 5169 |
| Commander ^(b) | 5824 | 150 | 5528 |
| Compass ^(b) | 6149 | 300 | 5774 |
| Flinders | 5380 | I.s.d. ($P = 0.05$) | 109 |
| GrangeR ^(b) | 5747 | | |
| La Trobe ^(b) | 4764 | | |
| Oxford | 5603 | | |
| Westminster ^(b) | 5063 | | |
| I.s.d. ($P = 0.05$) | 177 | | |

Parkes

GrangeR^(b) was the highest yielding variety at Parkes and Buloke^(b) the lowest yielding. Grain yield increased with the application of 30 kg N/ha and increased further with application of 90 kg N/ha. There was a general yield increase in all varieties as a result of increasing target plant population from 75 to 150 plants/m² and then to 300 plants/m² (Table 4).

Table 4: Effect of variety choice, nitrogen rate, target plant population on grain yield (kg/ha) of barley at Parkes in 2014

| Variety | Yield | N (kg/ha) | Yield | Plants/m ² | Yield |
|--------------------------|-------|-----------------------|-------|-----------------------|-------|
| Bass ^(b) | 3900 | 0 | 3769 | 75 | 3805 |
| Buloke ^(b) | 3723 | 30 | 4087 | 150 | 4094 |
| Commander ^(b) | 4167 | 90 | 4337 | 300 | 4294 |
| Compass ^(b) | 4090 | I.s.d. ($P = 0.05$) | 172 | I.s.d. ($P = 0.05$) | 43 |
| Flinders ^(b) | 4105 | | | | |
| GrangeR ^(b) | 4389 | | | | |
| La Trobe ^(b) | 4163 | | | | |
| Wimmera ^(b) | 3975 | | | | |
| I.s.d. ($P = 0.05$) | 280 | | | | |

Condobolin

There were significant differences in grain yield between varieties at Condobolin, with Compass^(b) the highest yielding variety and GrangeR^(b) the lowest yielding (Table 5).

Table 5: Grain yield of eight barley varieties (across all nitrogen and plant population treatments) at Condobolin in 2014

| Variety | Grain yield (kg/ha) |
|--------------------------|---------------------|
| Bass ^(b) | 2002 |
| Buloke ^(b) | 1890 |
| Commander ^(b) | 2018 |
| Compass ^(b) | 2398 |
| Flinders ^(b) | 2030 |

| Variety | Grain yield (kg/ha) |
|-------------------------|---------------------|
| GrangeR ⁽¹⁾ | 1762 |
| La Trobe ⁽¹⁾ | 2236 |
| Wimmera ⁽¹⁾ | 2185 |
| I.s.d. ($P = 0.05$) | 160 |

There was a significant interaction between seeding rate and N rate at Condobolin (Figure 5). Increasing target seeding rate from 75 to 150 plants/m² resulted in increased grain yield at all N levels. A further plant population increase to 300 plants/m² resulted in no change in grain yield for the nil and 30 kg N/ha rates but yield was reduced at the 90 kg N/ha rate. The combination of high N rates and a high population was excessive in the relatively dry environment at Condobolin.²⁹

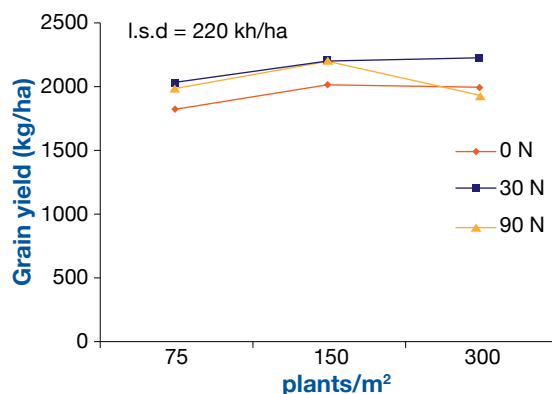


Figure 5: Interaction between nitrogen rate and plant population on grain yield of barley at Condobolin in 2014.

More information

GRDC Update Papers:
[Barley agronomy in southern NSW](#)

5.9.2 Nitrogen supply and grain protein content

Nitrogen is a primary constituent of protein; therefore, adequate soil N supply is essential for producing cereal grain protein. Supply of N is shaped by a number of factors in the farming system (Figure 6) and the N cycle (Figure 7).

²⁹ R Brill, K Moore, I Menz, N Moody (2015) Barley agronomy in southern NSW. GRDC Update Papers, 10 February 2015, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Barley-agronomy-in-southern-NSW#sthash.wDtGvdXs.dpuf>

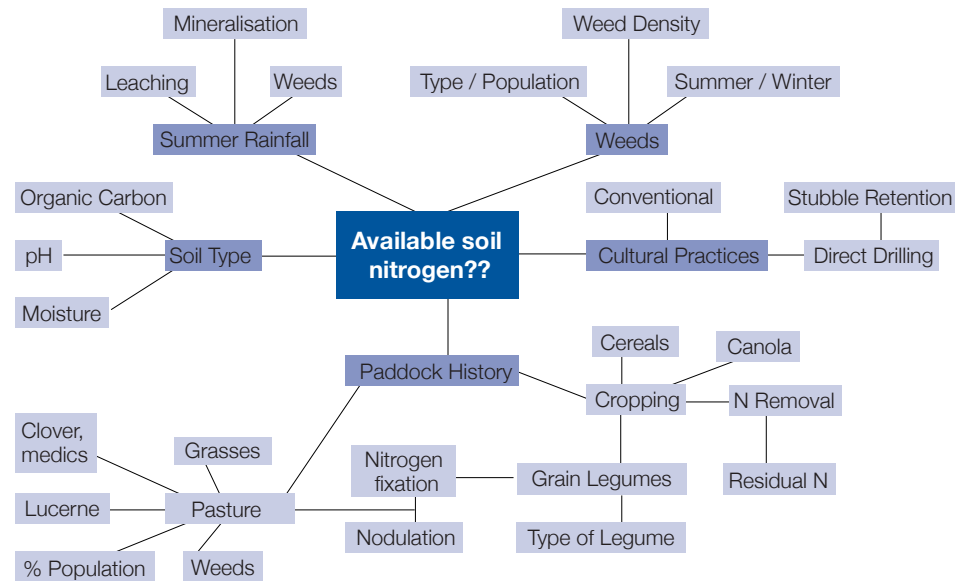


Figure 6: Factors influencing available soil nitrogen. (Source: Incitec Pivot Ltd)

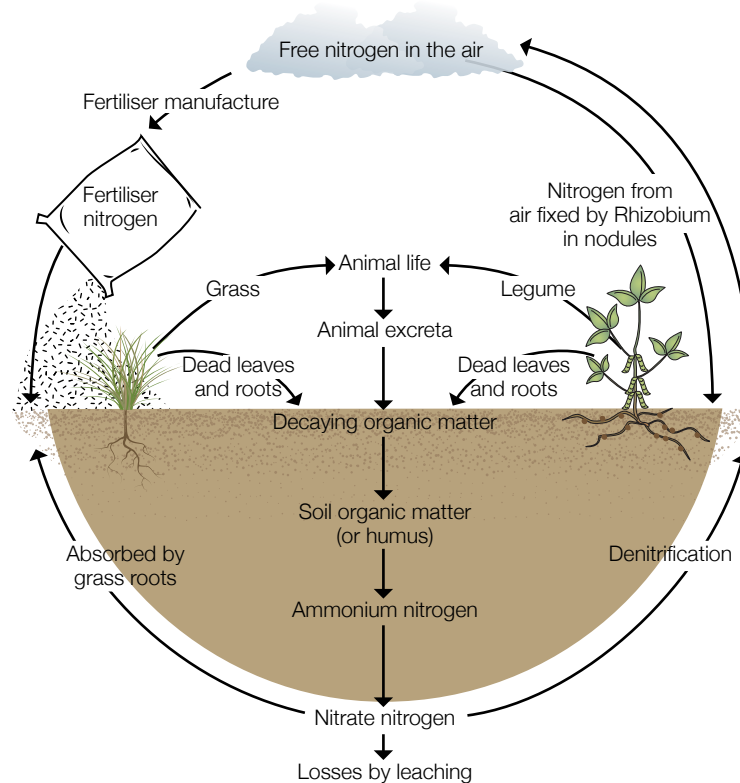


Figure 7: The soil nitrogen cycle.

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 advisers are a good source of support in determining fertiliser application strategies.³⁰

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 8)). 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.

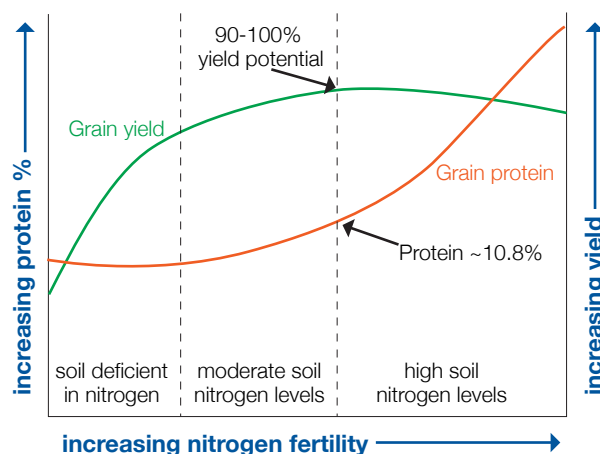


Figure 8: Relationship between grain yield and protein. (Source: Incitec Pivot Ltd)

i More information

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

[GRDC: Managing legume and fertiliser N for northern grains cropping](#)

5.9.3 Nitrogen deficiency symptoms

Description:

- Plants are pale green with reduced bulk and tiller formation (Figures 9 and 10).
- Symptoms first occur on the 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.

³⁰ Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>



Figure 9: Adequate (left) and inadequate (right) nitrogen nutrition. (Photo: Mel Mason, Agriculture WA)³¹



Figure 10: Inadequate nitrogen nutrition expressed as pale green plants with reduced bulk and tiller formation.

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.

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 N_2 fixed. High N loss occurs by leaching in high-rainfall areas and sandy soils.³²

³¹ GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

³² GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

5.9.4 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 ammonium ions (NH_4^+). If there are insufficient adsorption sites at the soil surface for the ammonium ions, ammonia (NH_3) 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.³³

Many farmers split the N application to barley crops between sowing, with mono- or di-ammonium phosphate (MAP, DAP), and early-mid-vegetation, with urea. Delaying N applications later in the season can affect protein requirements. Splitting N application between sowing and in-crop allows growers to lower their financial risk 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 the N all really lost to the air in a couple of days? Published 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.

Researchers have detailed the factors that drive the process of N volatilisation from fertiliser. 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 (CaCO_3). 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.³⁴

³³ Incitec Pivot Limited, <http://www.incitecpivot.com.au/>

³⁴ 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>

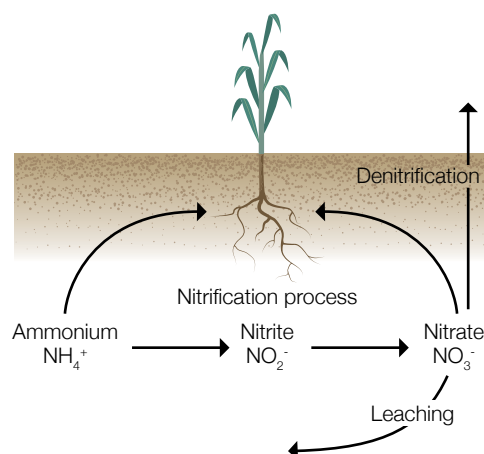


Figure 11: The nitrification process.

Saturated soil conditions between fertiliser application and crop growth can lead to significant N losses from the soil through denitrification (Figure 11). The gases lost can be nitric oxide (NO), nitrous oxide (N₂O) and di-nitrogen (N₂). 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.³⁵

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.³⁶

More information

[GRDC Update Papers: Nitrogen volatilisation from northern cropping soils](#)

More information

[CSS of SA: S and N fertilisation in Mallee barley crops: 2012 trial results](#)

[Farming Ahead: S&N—adding bounce to Mallee barley](#)

[MSF: Barley agronomy update, Karoonda Information Booklet 2013 \(pp. 31–33\)](#)

[MSF: Sulfur and Nitrogen responses of barley in Mallee 2013](#)

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

5.9.5 Nitrogen-use efficiency

Efficient use of N is crucial to economic production of cereals. 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.³⁷

5.9.6 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.

³⁵ 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>

³⁶ 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>

³⁷ R Brill, M Gardner, G McMullen (2012) Comparison of grain yield and grain protein concentration of commercial wheat varieties. GRDC Update 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>

in focus

5.9.7 Effectiveness of late nitrogen application

Results of a GRDC-funded Southern Farming Systems 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.
- 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 face 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 12 below.³⁸

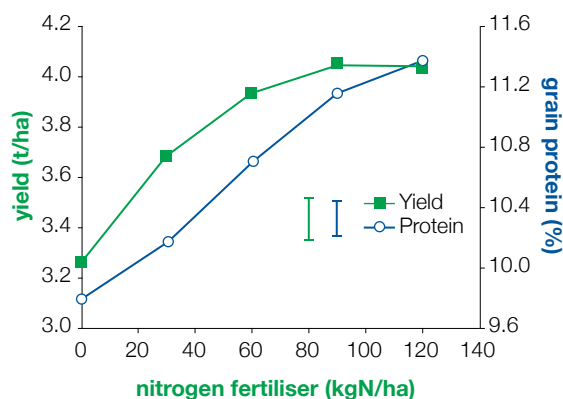


Figure 12: Grain yield (t/ha) and protein concentration (%) from 10 wheat varieties with varying rates of applied nitrogen (Brill et al. 2012).

³⁸ 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

5.10 Current general in-crop nutritional levels for nitrogen

To meet malt specifications, growers should target protein levels of 10.5–12% to achieve maximum yield and still meet receival standards. As the rate of N supply is increased, yield will generally increase to a maximum level, whereas protein may continue to increase with further N application. Drier or wetter than expected seasonal conditions can significantly change yield potential mid-season, which consequently changes N requirements to meet target protein contents.³⁹

infocus

5.10.1 Barley nutrition and agronomy—do we need sulfur and nitrogen?

- Cereal requirement for S is much less than for canola.
- Responses to N are more common than to S in Mallee cereals; therefore fertiliser expenditure should reflect this.
- A balanced approach to nutrition for both S and N is required in the Mallee.
- Soil sampling at depth is critical for nutrient budgeting because S may be deficient in the top 10 cm but adequate at depth.
- Requirements for S should be locally assessed on a paddock-to-paddock basis; consider fertiliser history, cropping rotation, product removal and soil test data.
- Crops deficient in S may be recovered by in-crop applications of sulfate of ammonia.
- Levels of S may be maintained by using S-enriched fertiliser sources (i.e. gypsum).

Introduction: Why the interest in sulfur?

Nitrogen and P are considered the two most limiting nutrients for cereal crop production in the Mallee. However, supply of S is increasingly being questioned. More canola is being grown than in the past, and a shift to high-analysis P-fertiliser products containing less background S (i.e. DAP or MAP, ~1–2% S, as opposed to the previously used single superphosphate, ~11% S) has led to suggestions that S deficiency is becoming more common. As part of a GRDC-funded Barley Agronomy Project, field trials were conducted throughout the Mallee in 2012 to assess barley growth and yield responses to S on sandy soils, with respect to rate, timing, and form of S.

Importance of nitrogen and sulfur

Both N and S are involved in the formation of proteins within the plant. However, the relative crop demand for these nutrients differs. The average total N demand for cereal and canola crops is quite similar, but canola requires approximately twice the amount of S that cereals require (Table 6). Cereals typically have a grain N:S ratio of 15:1 whereas canola has a grain N:S ratio of 7:1. In cereals, lower S levels lead to lower protein and reduced flour quality, and can cause significant yield losses in deficient conditions. There is little information to support widespread yield responses to S in cereals in the Mallee; however, there are well-documented cases of S yield responses in canola.

³⁹ N Fettell, P Bowden, T McNee, N Border (2010) Barley Growth & development, PROCROP. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

Table 6: Approximate nitrogen and sulfur requirements for cereal, pulse and canola crops (nutrient kg/ha)

| Crop | Nitrogen | Sulfur |
|------------|----------|--------|
| Wheat | 23 | 1.5 |
| Barley | 20 | 1.4 |
| Canola | 40 | 5 |
| Field peas | 37 | 2 |

Decisions on N and S fertiliser

The fundamentals of fertiliser management for N and S are similar. Demand can be estimated through a budget approach. A deep soil test (10–60 cm) can be used to estimate the soil N and S content at seeding. For all budgeting equations, first determine a target yield and protein, because crop yield potential is the driver of N and S requirement. Crop N demand can then be estimated by using tools such as an N calculator, [Yield Prophet®](#), and relevant calculations that factor in soil, seasonal, and soil N mineralisation.

The current recommendation for soil S testing is the KCl-40 method, which is taken in the top 0–10 cm. However, S is often located deeper in the profile. Plants take up S in the sulfate form, which is water-soluble and is mobile in the soil (like N) and readily leached. Sandy soils are generally lower in nutrients (N, S) and more prone to leaching from large rainfall events; hence the need for deep soil testing.

Sulfur responses in 2012

The 2012 trials in the Mallee demonstrated a lack of S-fertiliser response at most sites. Three of four trials showed no response to S, despite the KCl-40 (0–10 cm) soil tests suggesting levels below the critical values (4–6 mg/kg) for cereal production at all sites (Table 7). Deep soil tests revealed sufficient S in the lower soil profile. This indicates that S is more accessible later in the season when roots explore the lower profile, and may explain the lack of S response at these sites.

Table 7: Topsoil (0–10 cm) and deeper soil (10–60 cm) sulfur and nitrogen test results from 2012 Mallee trial sites, taken pre-sowing from each replicate (3 cores bulked X 3 replicates)

| Site | pH (CaCl ₂) | Depth (cm) | S (KCl-40) (mg/kg) | Available S (kg/ha) | Available N (NO ₃ ⁻ , NH ₄ ⁺) (kg/ha) |
|-------------|-------------------------|------------|--------------------|---------------------|------------------------------------------------------------------------------------|
| Lameroo | 7.8 | 0–10 | 2.9 | 3.48 | |
| | 8.1 | 10–60 | 2.2 | 13.2 | 38.7 |
| Murrayville | 7.3 | 0–10 | 1.9 | 2.28 | |
| | 8.4 | 10–60 | 2.3 | 13.8 | 42 |
| Paruna | 6.5 | 0–10 | 3.6 | 4.32 | |
| | 8.1 | 10–60 | 1.4 | 8.4 | 35.6 |
| Karoonda | 7.3 | 0–10 | 1.8 | 2.16 | |
| | 8.3 | 10–60 | 17 | 102 | 36.6 |

These results are supported by literature suggesting that 0–10 cm KCl-40 is not always an accurate measure of crop S supply, and that a total approach similar to deep soil-N testing maybe more informative. Testing for S can be done in conjunction with nitrate tests at a small additional cost.

Deficiency of S may not be as widespread in the Mallee as first thought but, rather, limited to certain paddocks as demonstrated by the Lameroo site (Table 8), where there was a response to combined N and S fertilisers. Concerned growers should conduct deep soil testing or tissue testing, or apply a test strip to diagnose potential S deficiency more accurately. Deficiency of S can be diagnosed in the field by general yellowing in the younger leaves, whereas the mobility of N within the plant means N deficiency is observed in the older leaves.

Table 8: Fertiliser effects on early vigour (normalised difference vegetation index, GS30) and grain yield in Hindmarsh⁽¹⁾ barley at Lameroo, Paruna, and Murrayville in 2012

n.s., Not significantly different at $P = 0.05$

| Treatment (kg/ha of nutrient) | Growth at GS30 (% nil control) | | | Grain yield (t/ha) | | |
|--------------------------------------------|--------------------------------|--------|-------------|--------------------|--------|-------------|
| | Lameroo | Paruna | Murrayville | Lameroo | Paruna | Murrayville |
| Nil | 100 | 100 | 100 | 2.13c | 1.63 | 1.21 |
| Gypsum (20 kg S) | 103 | 105 | 96 | 2.14c | 1.65 | 1.21 |
| Urea (17.5 kg N) | 123 | 125 | 116 | 2.70b | 1.58 | 1.19 |
| Sulfate of ammonia (17.5 kg N, 20 kg S) | 123 | 123 | 112 | 2.96a | 1.69 | 1.14 |
| Urea (17.5 kg N) + gypsum (20 kg S) | 122 | 119 | 114 | 2.68b | 1.54 | 1.08 |
| I.s.d. ($P = 0.05$) | 10.1 | 9.8 | 12.2 | 0.24 | n.s. | n.s. |

Nitrogen responses in 2012

Overall, N was the key nutrient driving early growth responses at all sites (Table 8) in 2012, and therefore the N balance was more important than S balance. Only at Lameroo was there a significant grain response to N, and an additional response to combined N and S (Table 8). The responses to N still depended on the deep soil N levels and seasonal site conditions.

Timing and form of nitrogen and sulfur application

The trial at Karoonda included additional treatments examining the effect of timing of application of N and S. Timing or form of N or S did not significantly change the yield response to fertilisation (Table 9). This is consistent with many experiments in South Australia that have found no consistent difference in the response to different forms of N fertiliser when applied at the same rate and timing. All yield responses to fertilisation could be explained by an N response, and not an S response.

A similar response to N was achieved across all three application timings. This response is not uncommon in Mallee farming systems, because DAP or MAP will supply a proportion of the N requirement, and the ongoing crop demand for N can be assessed throughout the growing season to better match seasonal conditions (soil moisture) with N supply. In lower yielding environments (<2.5 t/ha), N applied at seeding or early in the vegetative stage has been generally found more effective than delaying N application to stem elongation. Nitrogen applied later in the growing season will tend to influence grain protein rather than yield. Trials suggests that 5–6 kg N per t grain per ha will increase grain protein levels by one percentage unit.

Table 9: Grain yield (t/ha), yield response (compared with nil fertilised control), and grain quality data of Hindmarsh⁽¹⁾ barley from the Karoonda nutrition trial in 2012

n.s., Not significantly different at $P = 0.05$

| Fertiliser treatment | Grain yield (t/ha) | Yield response (t/ha) | Protein (% dry basis) |
|---------------------------------------------------|-----------------------|-----------------------------|--------------------------|
| Nil N fertilised control | 0.80 | 0.00 | 11.8 |
| Nil N + gypsum (20 kg S) | 0.78 | -0.02 | 11.1 |
| Urea at sowing (17.5 kg N) | 1.12 | 0.32 | 11.4 |
| Urea +gypsum at sowing (17.5 kg N, 20 kg S) | 1.24 | 0.44 | 11.7 |
| Sulfate of ammonia at sowing (17.5 kg N, 20 kg S) | 1.20 | 0.40 | 12.3 |
| Sulfate of ammonia at 3-leaf (17.5 kg N, 20 kg S) | 1.15 | 0.35 | 11.1 |
| Sulfate of ammonia at GS22 (17.5 kg N, 20 kg S) | 1.38 | 0.58 | 12.2 |
| I.s.d. ($P = 0.05$) | | 0.26 | 1.7 |

Conclusions

Nitrogen was the main nutrient driving growth in these trials (although not underestimating the importance of S). Responses to N were more common than responses to S in Mallee cereals; fertiliser expenditure may be better targeted towards correcting N deficiencies first. Development of S deficiencies will depend on fertiliser history, crop rotation, and product removal and these should be considered on a paddock-by-paddock basis within a long-term nutrition program. Sulfur deficiency can be recovered by in-crop application of sulfate of ammonia, or avoided with a longer term strategy using alternate sources of S (Table 10).

Table 10: Sulfur content of commonly used fertilisers

| Fertiliser form | % Sulfur |
|-----------------------------|----------|
| Superphosphate | 11 |
| Sulfate of ammonia | 24 |
| Agricultural gypsum | 16–18 |
| Triple superphosphate (TSP) | 1.5 |
| Di-ammonium phosphate (DAP) | 1.0 |

Nutrition responses are largely driven by seasonal and site conditions and so trials are ongoing. Nonetheless, the results highlight the importance of a balanced approach to nutrition and the need for soil sampling at depth in the Mallee for both S and N.⁴⁰

5.11 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 barley. 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. 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 barley anticipated. The application is then adjusted in the light of soil test results.⁴¹

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 Decisions 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.

On highly calcareous soils (Calcarosols), the DGT-P soil test provides a better prediction of crop response to fertiliser than Colwell-P.⁴²

⁴⁰ K Parker, R Wheeler (2013) Barley nutrition and agronomy—do we need sulphur and nitrogen? GRDC Update Papers, 15 August 2013, <https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/08/Barley-nutrition-and-agronomy>

⁴¹ Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

⁴² 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>

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](#)

5.11.1 Phosphorus deficiency

Description (Figures 13 and 14):

- 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.⁴³

More information

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

[GRDC Update Papers: Subsoil manuring](#)

Phosphorus deficiency is one of the most widespread of nutrient deficiencies. Phosphorus is an important component of many molecules in plant cells and is therefore important for growing tissue, where cells are actively dividing (e.g. during development of seedling roots, flowering and the formation of seed). Phosphorus-deficient plants are stunted and dark green with short, erect leaves and stout stems that often develop orange, red or purplish discoloration. Many soils in cereal-growing areas will respond to the application of phosphate fertilisers.⁴⁴



Figure 13: Adequate (left) and inadequate (right) phosphorus nutrition. (Photos: Nigel Wilhelm, SARDI)⁴⁵

⁴³ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

⁴⁴ 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>

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

Similar symptoms

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

5.11.2 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. Hence, it is important to apply 'starter fertilisers' with the seed.

Subsequent P requirement is much larger, and largely mirrors the accumulation of crop biomass. As a rule, crops require ~5 kg P plant-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 (Table 11).

The need for P fertiliser can be determined by using soil tests (0–10 and 10–30 cm) and/or test strips of fertiliser.⁴⁶

More information

GRDC Fact Sheets: Soil testing for crop nutrition (Southern Region)

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

Table 11: 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 |

5.11.3 Phosphorus availability

A key consideration for growers with regard to fertiliser management is how much P will be supplied by the stubble, 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.

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 considering 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 the stubble and microbial uptake and release. The presence of different chemical P forms in the stubble is also likely to influence the proportion of P that undergoes direct release or microbial uptake and decomposition.

Research indicates 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.⁴⁷

5.11.4 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 12 shows the actual rate of fertiliser product required to apply various rates of P.

Table 12: 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 |

⁴⁷ S Noack, M McLaughlin, R Smernik, T McBeath, R Armstrong (2012) The value of phosphorus in crop stubble. GRDC Update Papers, 23 February 2012

5.11.5 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 15 shows wheat roots responding to a band of P 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.

Technologies such as computer-aided tomography 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 P in moist soil.⁴⁸

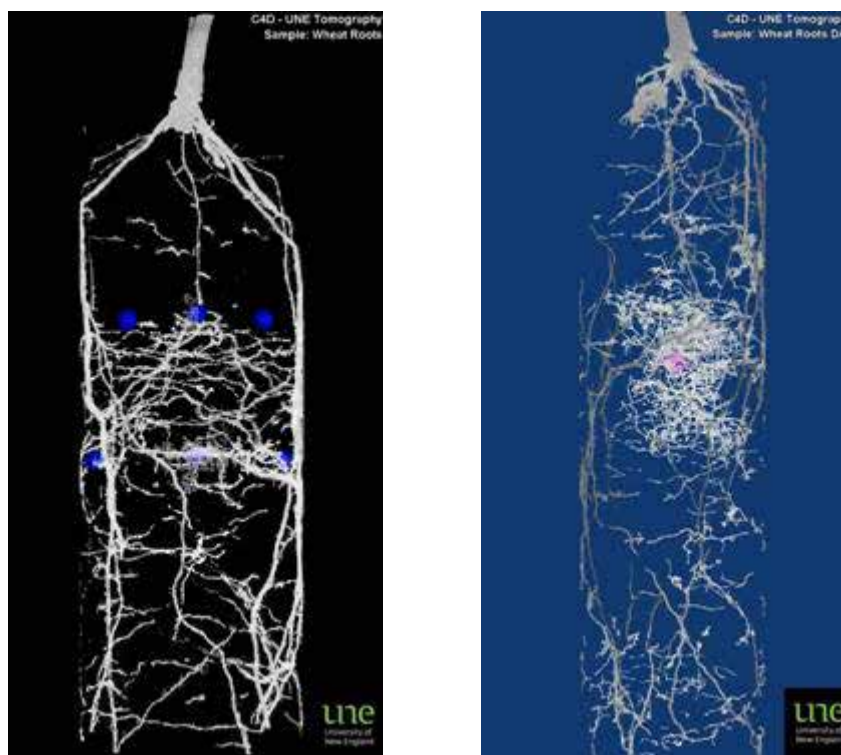


Figure 15: 3D Computer-aided tomographs of cereal root systems supplied with P in a diffuse band (left panel) or in a granule (right panel) after 30 days of growth.

5.11.6 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.

⁴⁸ 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>

More information

[Research paper: Responsiveness of wheat \(*Triticum aestivum*\) to liquid and granular phosphorus fertilisers in southern Australian soils](#)

Research in South Australia on highly calcareous soils (20–90% CaCO₃) has shown benefits of using liquid fertilisers over the traditional granular forms. Researchers reported on dry matter responses to liquid and granular P fertilisers from soils collected from around Australia. The findings suggested that liquid P fertilisers also have potential applications in non-calcareous soils.⁴⁹

Trials in New South Wales found no difference between the types of fertiliser (liquid or granular) used with respect to plant growth or grain yield. It was concluded that when deciding whether to use liquid P fertilisers the additional cost of equipment needs to be taken into account.⁵⁰

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 that of traditional fertiliser, and should be added to budget comparisons.⁵¹

5.12 Sulfur

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

Sulfur inputs to cropping systems have declined with the use of low-S fertilisers: triple superphosphate, MAP and DAP. 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.⁵²

5.12.1 Deficiency symptoms

- Crops grow poorly, lack vigour and mature more slowly; reduced tillering, low grain yields and protein.
- Initially all leaves are pale green, but old leaves darker green (Figures 16 and 17).
- Youngest leaves turn pale yellow and eventually white; whole leaf is affected not just the area between the veins.
- Leaves generally do not die even when they have turned white.
- Old leaves remain green.

⁴⁹ TM McBeath *et al.* (2007) Predicting the response of wheat (*Triticum aestivum* L.) to liquid and granular phosphorus fertiliser in Australian soils. Australian Journal of Soil Research 45, 448–456, <http://www.publish.csiro.au/paper/SR07044.htm>

⁵⁰ 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

⁵¹ 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>

⁵² 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>

- In some varieties, margins and sheaths of old leaves become red or purple-red.⁵³

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.⁵⁴

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 S mineralisation and uptake. Acid sandy soils are subject to S leaching. Fertilisers such as DAP and MAP are low in S.⁵⁵

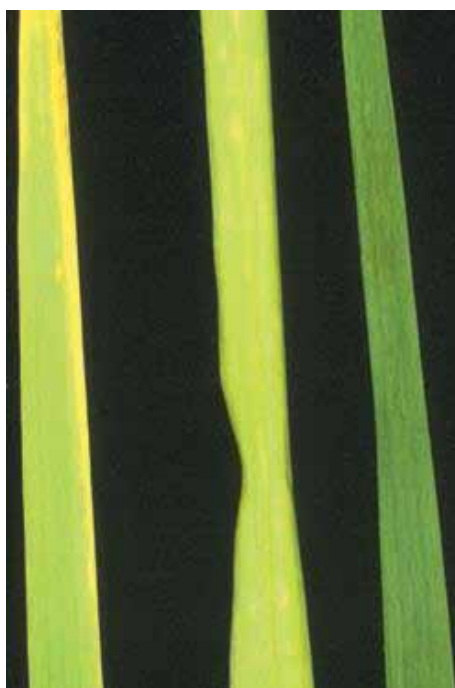


Figure 16: Sulfur-deficiency symptoms on barley leaves (left and middle); adequate nutrition (right). (Photo: Hungry Crops, DAF Qld)

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>

⁵⁴ 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>

⁵⁵ 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 17: Sulfur-deficient barley plant (left); plant with adequate nutrition (right). (Photo: Noel Grundon, DAF Qld)

5.13 Potassium

Potassium 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.⁵⁶

In the Southern Region, cropping soils are generally unresponsive to additions of K. However, as crops continue to mine K from soils, this may change. 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.

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.⁵⁷

5.13.1 Deficiency symptoms

- Stunted plants with short, stout stems and pale yellow-green stems and leaves; appear limp or wilted.
- Symptoms develop first on old leaves, but eventually move to younger leaves.
- Tips of old leaves become dark yellow, moving down the edges of the leaves.

⁵⁶ 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>

⁵⁷ 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.

- Yellow areas die and turn grey.
- In some varieties, dark brown spots and streaks appear in the yellow areas or the green tissue close by; eventually the whole leaf becomes yellow, dies and turns pale to dark brown (Figure 18).⁵⁸



Figure 18: Barley leaf on the right shows adequate potassium nutrition; the others show inadequate K. (Photo: Noel Grundon, QDPI)⁵⁹

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.⁶⁰

5.13.2 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.

Potassium is effectively immobile in the soil (like P), so profiles tend 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 testing 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.

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>

⁵⁹ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

⁶⁰ 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

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

Once K fertility of the surface layers has been restored, deep application of K fertilisers is best for maintaining 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.⁶¹

5.14 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.
- 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.⁶²

5.14.1 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 barley are <14 mg/kg.⁶³ Zinc supplements can be applied with fertiliser as zinc oxide, chelated Zn or zinc sulfate. The products can also be used for foliar applications. Product efficacy varies with the time and placement of application.⁶⁴

Deficiency description (Figures 19 and 20):

- 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.

⁶¹ 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>

⁶² GRDC (2013) Micronutrients. Crop Nutrition Fact Sheet GRDC, 4 November 2013, <http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients>

⁶³ R Norton (2014) What's new with zinc; maybe just some critical reminders. GRDC Update Papers, 11 February 2014, <https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Whats-new-with-zinc-maybe-just-some-critical-reminders>

⁶⁴ 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>

- 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 (especially Group B) 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.⁶⁵



Figure 19: Zinc deficiency in barley. (Photos: DAFWA)



Figure 20: Zinc deficiency symptoms on barley leaves. (Photo: DAFWA)

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>

5.14.2 Copper

Copper is essential for chlorophyll formation and pollen production. 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 are high levels of iron (Fe), Mn or Al in the soil. Critical tissue levels have been reported as <1.5 mg/kg in the youngest expanded blade in wheat.⁶⁶

Deficiency symptoms in barley are depicted in Figures 21–24. In the paddock:

- Before head emergence, deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green healthy crop.
- After head emergence, mildly affected areas have disorganised wavy heads. Severe patches have white heads and discoloured late maturing plants.
- Symptoms are often worse on sandy or gravelly soils, where root-pruning herbicides have been applied and recently limed paddocks.

On the plant:

- Youngest growth is affected first and most severely.
- The first sign of Cu deficiency before flowering is growing point death and tip withering, and/or bleaching and twisting of up to half the length of young leaves.
- The base of the leaf can remain green.
- Old leaves remain green and seemingly healthy.
- Tiller production may increase but they die prematurely.
- Heads may be white and withered or have a rat-tail appearance.
- Maturity is delayed and very late tillers may be present.
- Stems are weaker, although in less severe cases, plant heads may be more erect. Severely deficient plants have few immature heads on weak and dirty stems.⁶⁷

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).⁶⁸

⁶⁶ 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>

⁶⁷ MyCrop. Diagnosing copper deficiency in barley. Department of Agriculture and Food WA, <https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-barley>

⁶⁸ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

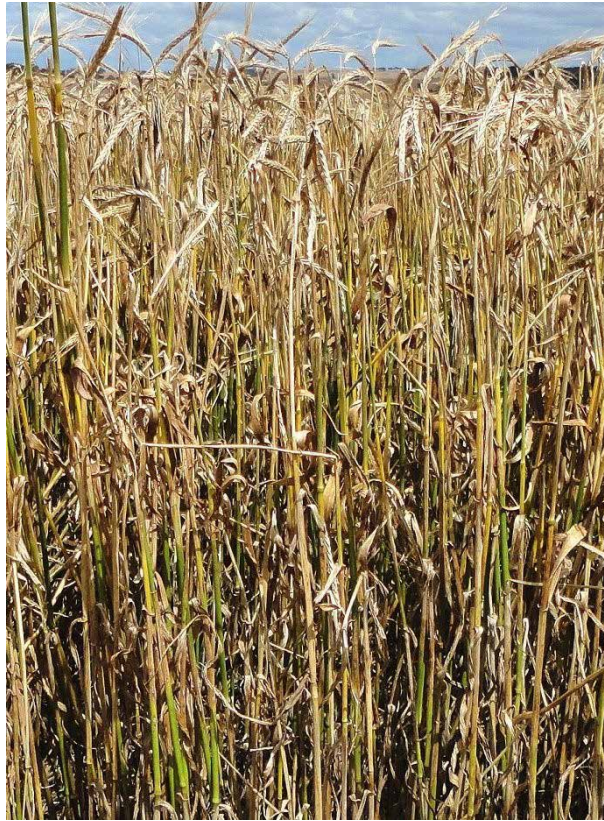


Figure 21: Copper deficiency in barley: head sterility causes delayed maturity. (Photo: DAFWA)



Figure 22: Copper deficiency symptoms on barley leaves. (Photo: Hungry Crops, DAF Qld)



Figure 23: Copper deficiency in barley: severely affected plants have no grain. (Photo: DAFWA)



Figure 24: Deformed barley heads indicating copper deficiency. (Photo: Nigel Wilhelm, SARDI)

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.⁶⁹

5.14.3 Boron

Boron deficiency

Key points:

- Boron is essential for germination and sugar metabolism.
- Symptoms of deficiency include stem splitting and poor grain set.
- 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:

- Stems are short and often fan-shaped; leaves are greyish-green.
- Dark brown, irregular spots occur on young leaves (Figure 25).
- Pale yellow areas in the middle of young leaves.
- Yellowing quickly moves towards the leaf tip and irregular, grey spots develop between the edge and mid-vein; spots often join, leaving grey dead tissue with vein unaffected.
- Eventually whole leaf tip dies turning grey-brown, with base of leaf remaining pale green.
- In severe deficiency, youngest leaves fail to develop or expand fully and sometimes die; leaves tear and tips die and turn grey.⁷⁰

Similar symptoms

Deficiency of Ca shows similar symptoms of youngest leaf damage but lacks grey lesions and the young leaf tip twists and dies.⁷¹

⁶⁹ 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>

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>

⁷¹ MyCrop. Diagnosing boron deficiency in barley. Department of Agriculture and Food WA, <https://www.agric.wa.gov.au/mycrop/diagnosing-boron-deficiency-barley>

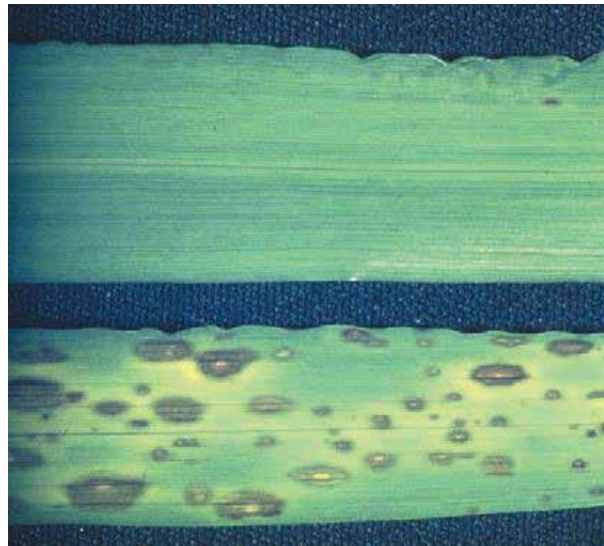


Figure 25: Symptoms of boron deficiency in barley (lower leaf). (Photo: Hungry Crops, DAF Qld)

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 26). Symptoms often do not appear in early vegetative growth.

Similar symptoms

Spot form of net blotch has similar symptoms but is not soil-type specific.

Contributing factors

Boron toxicity can occur with high boron levels in subsoil and when growing boron-intolerant varieties.⁷²



Figure 26: Symptoms of boron toxicity on barley leaves: Hamelin[®] (left), Mundah[®] (right). (Photo: DAFWA)

⁷² GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

5.14.4 Iron

Key points:

- Iron is an essential component of chlorophyll and respiratory enzymes.
- 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:

- Plants are stunted with thin, spindly stems and pale green to yellow leaves (Figures 27 and 28).
- Youngest leaves turn pale green.
- Leaves develop yellow (between the veins) and green (veins) stripes down the length of the leaf (interveinal chlorosis).
- In severe deficiency, yellow stripes may turn almost white, but do not die; veins become pale green to yellow; tillering reduced and young tillers die.
- Old leaves remain pale green.

Similar symptoms

Deficiencies of N and S result in pale plants; *Barley yellow dwarf virus* causes yellow stripes.

Contributing factors

Contributing factors include highly calcareous soils and waterlogged conditions.⁷³

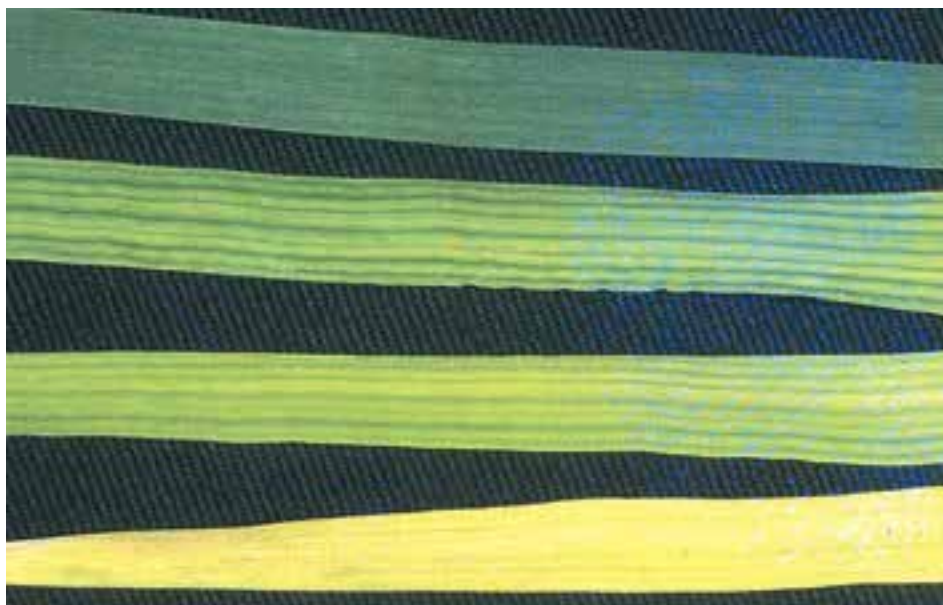


Figure 27: Iron deficiency on wheat leaves, showing prominent green veins (symptoms are similar in barley). (Photo: Hungry Crops, QDPI)

⁷³ 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 28: Iron deficiency in wheat crop (symptoms are similar in barley). (Photo. Mark Seeliger, PIRSA)

5.14.5 Manganese

Manganese deficiency

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:

- Deficiency often appears as patches of pale, floppy plants in an otherwise green, healthy crop.
- Pale green stripes usually develop on young leaves; blotches develop that may have a thin brown rim (Figure 29).
- Leaves are weak and tear easily.
- Tillering is greatly reduced with extensive leaf and tiller death (Figure 30). With extended deficiency, the plant may die.
- Surviving plants produce fewer and smaller heads.



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



Figure 30: Manganese deficiency in barley crop (left); adequate (right). (Photo: Nigel Wilhelm, SARDI)

Similar symptoms

Zinc deficiency causes patches of pale stunted plants but not 'floppy'.

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.⁷⁴

⁷⁴ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

Manganese toxicity

Manganese toxicity symptoms include grey flecks or either yellow or brown spots developing on leaves (Figure 31).

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.⁷⁵



Figure 31: Manganese toxicity in barley (left and middle) compared with healthy leaf (right). (Photo: Hungry Crops, DAF Qld)

5.14.6 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.
- Levels < 0.075 mg/kg in the youngest fully emerged leaf indicate deficiency.⁷⁶
- Very small quantities (50 g Mo/ha) applied with fertiliser are usually sufficient, usually in the form of molybdenum trioxide. Sodium or ammonium molybdate can be used as sprays.⁷⁷

⁷⁵ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

⁷⁶ MyCrop. Diagnosing molybdenum deficiency in cereals. Department of Agriculture and Food WA, <https://www.agric.wa.gov.au/mycrop/diagnosing-molybdenum-deficiency-cereals>

⁷⁷ Incitec Pivot. Molybdenum fact sheet. Fertfacts. Incitec Pivot, <http://www.incitecpivotfertilisers.com.au/en/Agronomy/-/media/Files/IPF%20Migration/FertFacts/MolybdenumFS/MolybdenumFSV3IPLLM15102009.ashx>



Figure 32: Wheat grown without (left) and with molybdenum (symptoms are similar in barley). (Photo: Snowball and Robson 1988)

Description of deficiency (Figure 32):

- 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

Stem and head frost damage causes shrivelled grain, late tillering.

Contributing factors

Factors include acidic soils, moderate to high levels of available soil N, and soils high in iron and aluminium oxides.⁷⁸

5.14.7 Magnesium

Description of deficiency (Figure 33):

- Young crops have poor growth with pale yellow leaves.
- In more mature crops, plants are stunted with thin spindly stems and pale yellow foliage marked with necrotic lesions.
- Old leaves develop elongated grey to brown spots near the edges, usually near the mid-section of the leaf. Lesions spread rapidly towards the tip and base of the leaf.
- With severe deficiency, old leaves turn brown and die.

Similar symptoms

Potassium and N deficiency symptoms include pale plants starting from the oldest leaf, but no grey-brown lesions.

⁷⁸ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

Contributing factors

Applications of high rates of high-quality lime can contribute. Magnesium deficiency is rare in broadacre agricultural crops.⁷⁹



Figure 33: Magnesium deficiency symptoms in barley. (Photos: Noel Grundon, DAF Qld)

⁷⁹ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>