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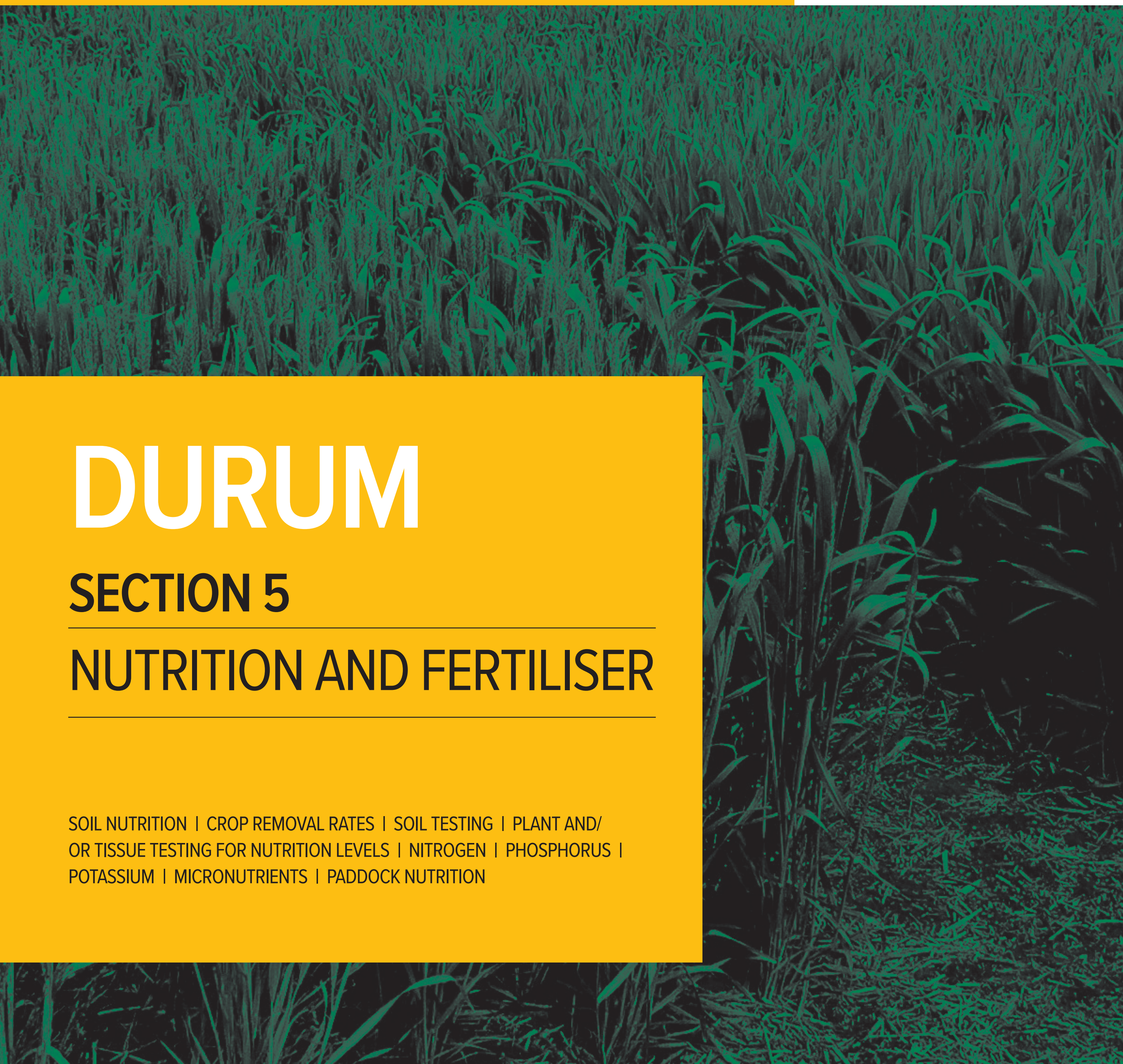

DURUM

SECTION 5

NUTRITION AND FERTILISER

SOIL NUTRITION | CROP REMOVAL RATES | SOIL TESTING | PLANT AND/OR TISSUE TESTING FOR NUTRITION LEVELS | NITROGEN | PHOSPHORUS | POTASSIUM | MICRONUTRIENTS | PADDOCK NUTRITION

Nutrition and fertiliser

Key messages:

- Soils require adequate nutritional properties to support yield targets.
- Previous plants and crops remove nutrients from the soil, which will need to be replaced by strategic rotations or chemical supplements.
- Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils.
- It is important to test soil for nitrogen to the effective rooting depth of the crop.
- Correct nitrogen application timing is essential. Too much nitrogen applied early can result in durum setting an unattainable yield potential with resultant high grain screenings levels. [1]
- Depending on location, other nutrients may need to be applied, such as phosphorus, sulfur and, on highly alkaline soils, zinc and manganese.

5.1 Soil nutrition

In south-eastern Australia profitable grain production depends on applied fertilisers, particularly nitrogen (N), phosphorus (P) and to a lesser extent, potassium (K), sulfur (S), zinc (Zn), manganese (Mn) and copper (Cu). [2] The natural fertility of cropped agricultural soils is declining over time. Grain growers must continually review their management programs to ensure the long term sustainability of high quality grain production.

Although crop rotations with grain legumes and ley pastures play an important role in maintaining and improving soil fertility, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed. The yield potential of a crop will be limited by any nutrient the soil cannot adequately supply. Poor crop response to one nutrient is often linked to a deficiency in another nutrient. Sometimes, poor crop response can also be linked to acidity, sodicity or salinity, pathogens or a lack of beneficial soil microorganisms. [3]

In the acid soils of southern Victoria poor wheat growth is often related to soil sodicity, excess acidity/high aluminium or Mn toxicity, or the physical constraints of waterlogging and high bulk density. [4] In the neutral and alkaline soils of north-west Victoria and the cropping areas of South Australia (SA), wheat production is principally constrained by excess alkalinity, salinity, sodicity or boron in subsoils.

There is a hierarchy of crop fertility needs: there must be sufficient plant-available N to get a response to P and there must be sufficient P for S and/or K responses to occur. Additive effects of N and P appear to account for most of the above-ground growth and yield response. [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 (soil water), or easily exchanged from the surface

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1 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

2 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

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

4 Conyers et al. 2003, MacEwan et al. 2010 in http://www.croppro.com.au/resources/Review%20-%20Soil%20constraints%20for%20wheat.doc

5 D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers. Grains Research and Development Corporation, March 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs

of clay and organic matter particles in the root-zone, and be supplied when and where the plant needs it. Temperature and soil moisture 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. [6]

With more frequent use of opportunity cropping, improved farming techniques and higher yielding varieties, nutrition programs should be reviewed regularly. 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. [7]

MORE INFORMATION

Ground Cover Issue 97: More profit from nutrition

VIDEOS

WATCH : Over the Fence: Precision agriculture pays at Mildura

5.2 Crop removal rates

Nutrients removed from paddocks will need to be replaced to sustain production. Table 1 illustrates the different levels of nutrients extracted in both irrigated and dryland scenarios. Growers need to adopt a strategy of programmed nutrient replacement based on yields and protein taken off paddocks. In durum, N is an essential nutrient to reach 13% protein. As a rule of thumb, for every tonne per hectare of high protein grain harvested, about 50 kg of N is removed in the grain. This amount of N must be replaced, together with other N losses such as from leaching and de-nitrification. [8]

Table 1: *Average nutrients removed by wheat crops (all figures are kg/ha).*

	Yield	N	P	K	Ca (calcium)	Mg (magnesium)	S	Zn
Irrigated wheat	7,000	125	24	35	3.5	10	3	200
Dryland wheat	2,000	40	7	10	1.5	2.8	5.5	60

Source: DAFF

5.3 Soil testing

Fertiliser is a major cost for grain growers, so making careful selections of crop nutrients is a major determinant of profit. Both under-fertilisation and over-fertilisation can lead to economic losses due to unrealised crop potential or wasted inputs. Before deciding on how much fertiliser to apply, it is important to understand the quantities of available nutrients in the soil, where they are located in the soil profile and the likely demand for nutrients in that season. Soil sampling to the full depth of root exploration prior to sowing should be a good guide to the available soil N supply. The values from appropriate soil tests can be compared against critical nutrient values and ranges; these indicate which nutrients are limiting or adequate. Soil test critical values advise growers if a crop is likely to respond to added fertiliser, but without further information they do not predict optimum fertiliser rates. When

6 DAFQ (2012) Wheat production: nutrition. Department of Agriculture and Fisheries Queensland, September 2012, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition

7 M Blumenthal, I Fillery (2012) More profit from crop nutrition. GRDC Ground Cover Supplement Issue 97. Grains Research and Development Corporation, March–April 2012, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-issue-97-MarApr-2012-Supplement-More-profit-from-nutrition/More-profit-from-crop-nutrition

8 R Hare (2006) Agronomy of the durum wheats Kamilaroi⦸, Yallaroi⦸, Wollaroi⦸ and EGA Bellaroi⦸. Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

considered in combination with information about target yield, available soil moisture, last year's nutrient removal and soil type, soil tests can help in making fertiliser decisions. [9]

Principal reasons for soil testing for nutrition:

- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity) and salinity, which affect crop demand as well as its ability to access nutrients;
- zoning paddocks for variable application rates; and
- as a diagnostic tool to identify reasons for poor plant performance. [10]

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; and
- 2 M KCl extractable inorganic N, which provides measurement of nitrate-N and ammonium-N. [11]

Sampling depth

Soil sampling to greater depth (0 to 60cm) is considered important for more mobile nutrients (N, K and S) as well as for pH, salinity and sodicity and boron which is often at toxic levels deeper in the soil profile in many low to medium rainfall cropping areas of southern Australia.

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 sub-sample is taken to the full sampling depth.
- Do not sample in very wet conditions.
- Shortcuts in sampling—such as taking only one or two cores, a handful or a spadeful of soil—will give misleading results. As a rule, 20 to 30 cores from a uniform soil zone in a paddock should be combined to make a single sample for testing.
- Avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers or other sources of nutrients such as sunscreen, which can contain zinc. [12]

MORE INFORMATION

Soil testing for crop nutrition – southern region factsheet.

5.4 Plant and/or tissue testing for nutrition levels

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

9 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

10 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

11 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

12 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

5.4.1 Why measure nutrients in plant tissues?

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

5.4.2 What plant tissue analysis shows

Plant tissue analysis shows the nutrient status of plants at the time of sampling. This, in turn, shows whether soil nutrient supplies are adequate. In addition, plant tissue analysis will detect unseen deficiencies and may confirm visual symptoms of deficiencies. Toxic levels also may be detected. Though usually used as a diagnostic tool for future correction of nutrient problems, plant tissue analysis from young plants will allow a corrective fertiliser application that same season. A plant tissue analysis can pinpoint the cause, if it is nutritional.

A plant analysis is of little value if the plants come from fields that are infested with weeds, insects, and disease organisms; if the plants are stressed for moisture; or if plants have some mechanical injury.

The most important use of plant analysis is as a monitoring tool for determining the adequacy of current fertiliser practices. Sampling a crop periodically during the season or once each year provides a record of its nutrient content that can be used through the growing season or from year to year. With soil test information and a plant analysis report, a producer can closely tailor fertiliser practices to specific soil-plant needs.

Do

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

Don't

- Avoid spoiled, damaged, dead or dying plant tissue.
- Don't sample plants stressed by environmental conditions.
- Don't sample plants affected by disease, insects or other organisms.
- Don't sample soon after applying fertiliser to the soil or foliage.
- Avoid sample contamination from dust, fertilisers, chemical sprays as well as perspiration and sunscreen from hands.
- Avoid atypical areas of the paddock, e.g. poorly drained areas.
- Do not sample plants of different vigour, size and age.
- Do not sample from different cultivars (varieties) to make one sample.

- Don't collect samples into plastic bags, as this will cause the sample to sweat and hasten its decomposition.
- Don't sample in the heat of the day, i.e. when plants are moisture stressed.
- Don't mix leaves of different ages. [13]

Once you start taking samples, it's critical to get the right plant part at the right growth stage (Table 2). A general rule of thumb is to use the most recently matured, fully developed leaf for more mature plants. For young plants, you can generally use the entire plant. For high-value crops, the petiole is used. [14]

Table 2: *Guidelines for sampling plant tissue in wheat.*

Growth stage to sample	Plant part	Number of samples required
Seedling to early tillering (GS 14–21)	Whole tops cut off 1 cm above ground	40
Early tillering to first node (GS 23–31)	Whole tops cut off 1 cm above ground	25
Flag leaf ligule just visible to boots swollen (GS 39–45)	Whole tops cut off 1 cm above ground	25
Early tillering to first node (GS21–31)	Youngest expanded blade plus next two lower blades	40

Source: Back Paddock Company

5.5 Nitrogen

Key points:

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

Nitrogen (N) is an essential nutrient for plant growth, development and reproduction. Despite N being one of the most abundant elements on earth, N deficiency is probably the most common nutritional problem affecting plants worldwide, as N from the atmosphere and earth's crust is not directly available to plants. N is so vital because it is a major component of chlorophyll, the compound through which plants use sunlight energy to produce sugars from water and carbon dioxide (i.e. photosynthesis). It is also a major component of amino acids, the building blocks of proteins. Without proteins, plants wither and die. Soil N exists in three general forms: organic N compounds, ammonium (NH4+) ions and nitrate (NO3-) ions. At any given time, 95–99% of the potentially available N in the soil is in organic forms: in plant and animal residues, in the relatively stable soil organic matter or in living soil organisms (mainly microbes such as bacteria). This N is not directly available to plants, but some can be converted to available forms by microorganisms. [15] In south-eastern Australia, many soils, especially light soils, are naturally deficient in N. [16] The N cycle in Figure 1 illustrates how N is converted between the many different forms.

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

14 The Fertiliser Institute (2016) Plant tissue analysis tells the story. http://www.nutrientstewardship.com/implementation/article/plant-tissue-analysis-tells-story#sthash.kUljaDGs.dpuf

15 The Mosaic Company (2016) Nitrogen in plants. Mosaic Crop Nutrition, http://www.cropnutrition.com/efu-nitrogen

16 CropPro. Nitrogen as a nutrient for wheat in southern Australia. http://www.croppro.com.au/resources/Review%20-%20Nitrogen%20for%20Wheat.pdf

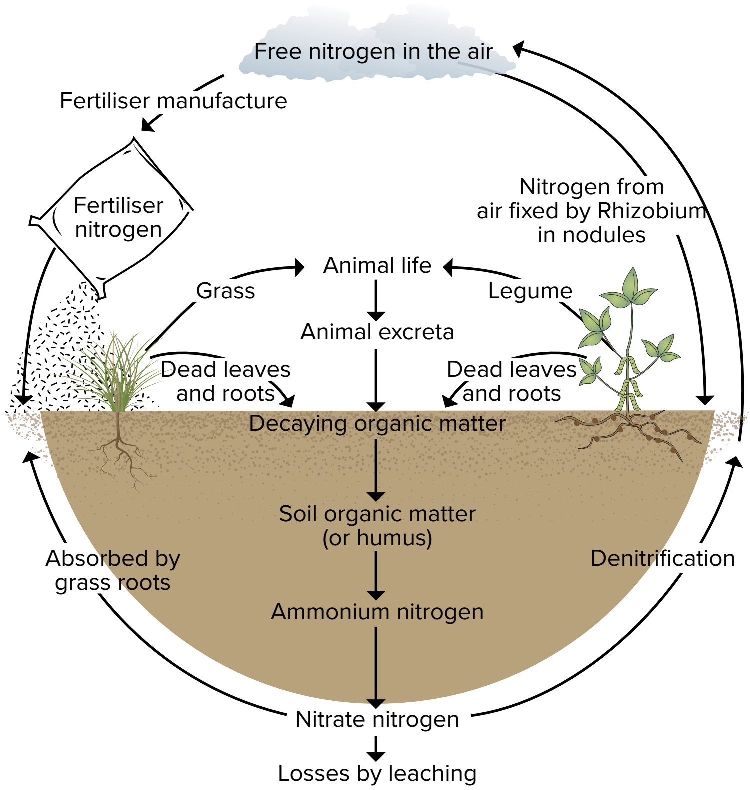

Figure 1: *The nitrogen cycle in soil, plants and the atmosphere.*

MORE INFORMATION

Nitrogen as a nutrient for wheat in southern Australia

Nitrogen management

FAQ

5.5.1 Nitrogen and durum

Crop nutrition is critical to the durum crop to achieve a high quality product. Nitrogen availability is an important constraint for durum production, because protein >12% in semolina is desired by pasta manufacturers. Nitrogen allows more photosynthesis by increasing the leaf area index and number of grains per spikelet, thus increasing grain yield. Nitrogen is essential for both optimum yield and grain protein content, and N applications are therefore required where N is deficient in the soil or with irrigation when high grain yield and protein are desired, as N requirements increase with increasing moisture availability. [17]

To obtain high protein levels soil N management requires careful planning. Paddocks with deep soil and high residual N fertility are suitable for growing dryland durum wheat. For the production of a 3 t/ha crop with 13% protein, access to 140 kg N/ha is necessary. [18]

5.5.2 Symptoms of nitrogen deficiency

Paddock:

- Light green to yellow plants particularly on sandy soils or unburnt header or windrows (Photo 1).
- Double sown areas have less symptoms if N fertiliser was applied at seeding. [19]

17 M Sissons, B Ovenden, D Adorada, A Milgate (2014). Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

18 DAFQ (2012) Durum wheat in Queensland. Queensland Department of Agriculture and Fisheries, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

19 DAFWA (2015) Diagnosing nitrogen deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1995

Photo 1: *N deficiency on unburnt header row.*

Source: DAFWA

Plant:

- Plants are pale green with reduced bulk and fewer tillers.
- Symptoms first occur on oldest leaf, which becomes paler than the others with marked yellowing starting at the tip and gradually merging into light green.
- Other leaves start to yellow and oldest leaves change from yellow to almost white (Photo 2).
- Leaves may not die for some time.
- Stems may be pale pink.
- Nitrogen deficient plants develop more slowly than healthy plants, but maturity is not greatly delayed.
- Reduced grain yield and protein levels. [20]

20 DAFWA (2015) Diagnosing nitrogen deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1995

VIDEOS

WATCH : GCTV14: N deficiency

Photo 2: *Nitrogen deficient plants are smaller with yellow leaves and fewer tillers.*

Source: Department of Agriculture and Food Western Australia

5.5.3 Predicting nitrogen supply

Predicting N supply to crops is complex. Nitrogen demand by the crop is related to actual yield, which is determined by seasonal conditions including the amount and timing of growing season rainfall. There is generally a poor relationship between pre-sowing soil test N and wheat yield response to applied N. This is usually due to the effect of stored water and in-season rainfall. For non-legume crops, crop N requirement and the ability of the soil to supply N depends on a range of variables, including inorganic and organic N content of the soil, in-crop mineralisation, rate of nitrate leaching, rotation history and presence of yield limitations (such as root disease) and abiotic constraints (such as salinity and sodicity). The pattern of crop demand for N during the growing season also has to be considered. The highest demand is when the crop is growing most rapidly. In-crop soil sampling can help identify how much N is being mineralised. Surrogate measurements of crop N using canopy sensors are a better alternative. Nitrogen fertiliser recommendations 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 aim 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. Yield Prophet requires a detailed characterisation of the physical and chemical properties of the soil profile explored by roots. [21]

21 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

5.5.4 Managing nitrogen levels

Key points:

- In environments where yields are consistently greater than 2.5 t/ha, N applications can be delayed until stem elongation without any loss in yield. In lower yielding environments, the chance of achieving a yield response similar to that achieved with an application at sowing is less.
- There is no consistent difference in the response to N between different forms of N fertiliser.
- In general, increases in grain protein concentration are greater with N applications between flag leaf emergence and flowering.
- Volatilisation losses can be significant in some cases and the greatest risk is with urea and lower with UAN and ammonium sulphate. [22]
- N-rich strips are a useful tool for showing crop N status and fertiliser needs. With mineralisation stable across and either side of the strip, it can indicate potential N response.

Rotations

Ideally durum should be planted into a rotation following a grain or pasture legume phase. Legumes and pasture species (e.g. field peas, faba beans, lupins, lentils, clover, *Medicago* spp.) convert atmospheric N to organic N through symbiotic relationship with bacterium. [23] Alternatively, use cropping history (Table 3) in conjunction with soil tests to calculate an N budget. It is important to test soil for N to the effective rooting depth of the crop. Nitrogen fertiliser is now an expensive input in farming systems, and so it is important for crop profitability that application rates are appropriate. Depending on the location, requirements for other nutrients may need to be managed, including P, S and, on highly alkaline soils, Zn. [24]

Table 3: *Effects of different rotations on soil total N (t/Ha) to 30 cm and as gain relative to continuous wheat.* [25]

		Soil total N	
Rotation	Wheat crops	0–30 cm	Gain
Grass/legume ley 4 years	0	2.91	0.55
Lucerne ley (1–2 years)	2–3	2.56	0.20
Annual medic ley (1–2 years)	2–3	2.49	0.13
Chickpeas (2 years)	2	2.35	0.00
Continuous wheat (4 years)	4	2.36	–

Fertiliser

Fertiliser rates should be aimed at producing a finished protein level at ADR1 (≥13%). The N harvested in the grain must be replaced, together with other N losses such as from leaching and de-nitrification. The amount of N fertiliser required can be calculated when the percentage of elemental N is known for the fertiliser product (e.g. urea N 46%, anhydrous NH3 82%). [26]

VIDEOS

Watch: Over the Fence West: Building soil nitrogen without the input costs

22 G McDonald, P Hooper P (2013) Nitrogen decision—Guidelines and rules of thumb, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/N-decision-Guidelines-and-rules-of-thumb

23 CropPro Nitrogen as a nutrient for wheat in southern Australia. http://www.croppro.com.au/resources/Review%20-%20Nitrogen%20for%20Wheat.pdf

24 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

25 Hossain SA, Dalal RC, Waring SA, Strong WM and Weston EJ (1996) Comparison of legume-based cropping systems at Warra, Queensland. I. Soil nitrogen accretion and status, Australian Journal of Soil Research 34: 273–287.

26 R Hare (2006) Agronomy of the durum wheats Kamilaroi⊕, Yallaroi⊕, Wollaroi⊕ and EGA Bellaroi⊕. Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

The use of split N applications can be used to achieve increases in biomass (grain yield), and if N is applied after the vegetative stages near to anthesis, this usually results in increases in grain protein content, grain protein yield, grain weight and HVK. [27] Large amounts of early applied N should be avoided in varieties with inherent small grain because it increases the risk of downgrading from small grain screenings. The new durum varieties require more N to achieve 13% protein, but this should only be applied as late as possible to minimise the potential for increased screenings. On sites both responsive and non-responsive to applied N, durum varieties have responded similarly in yield and in many quality measurements with applied N, but they have shown large differences in grain screenings. The new varieties are also able to yield higher than the older varieties with the same amount of N supply, often resulting in lower grain protein. [28]

IN FOCUS

GRDC Final Report – Durum expansion in SA through improved agronomy – when to apply nitrogen

Across all N trials in SA's South East, Mid North and Yorke Peninsula regions, Hyperno⍉ and Yawa⍉ have been downgraded the most frequently for low grain protein. As a result, growers may need to apply more N to achieve ADR1 grade. In 2011, an additional 40 kg/N (additional to 80 kg/N previously applied in other varieties) was applied at flag leaf emergence, resulting in 13% protein and ADR1 in higher yielding lines Hyperno⍉ and Yawa⍉ at Bordertown and Paskeville. The trials have shown that while the amount of N is important, the timing of the N application is equally as important, particularly with respect to grain size. One of the challenges in achieving 13% grain protein in a variety such as Yawa⍉ is managing the increased sensitivity in screening levels that occur with applied N, and when grain protein increases. Large amounts of N applied early, before growth stage (GS) 31, have predisposed Yawa⍉—with its inherently small grain—to quality downgrading because of high screenings, whereas varieties with inherently larger grain (Tjilkuri⍉ and Caparoi⍉) were not downgraded across early N treatments and appear to be less sensitive to an oversupply of early N. Across all trials, the most effective method to apply more N and reduce the likelihood of quality downgrading (by maintaining grain size) was to adopt a strategic approach to applying N (e.g. later in the growing season or with split applications). An example of this was at Hart in 2011, where applying N later than the onset of stem elongation meant the extra N was translocated to grain protein. Applying N earlier resulted in increased vegetative growth. Too much early vegetative growth results in more water use, and can potentially set an unattainable yield potential (more grains/ m^2). Both factors predispose crops to smaller grain if spring conditions are less favourable. Growers are concerned that if N is applied late they may be missing out on achieving maximum yields, but across all trials the maximum yields in durum appear to be achieved in the range of a minimum 10.5–11% protein. Growers, therefore, only need to apply enough N before stem elongation to achieve a 10.5-11% protein in their target yield potential; additional N (e.g. oversupply) during this period may only predispose some varieties to quality downgrading from small grain screenings. The extra N needed for grain protein can be applied later from flag leaf emergence and reassessed based on seasonal conditions. [29]

27 M Sissons, B Ovenden, D Adorada, A Milgate (2014). Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

28 GRDC (2012) Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DGA00001

29 GRDC (2012) Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DGA00001

Timing of application

Grain yield improvements are mainly caused by increased tiller numbers and grains per ear, both of which are determined early in the life of a wheat plant. A sufficient supply of N during crop emergence and establishment is critical. N use efficiency can be improved by delaying fertiliser application until the crop's roots system is adequately developed. This can be three to four weeks after germination.

Later N applications can also have yield benefits through increased tiller survival, leaf duration and photosynthetic area. Delaying application however, reduces the chance that economic response to N will be achieved. An advantage of late applications at GS 31 (1st node visible) is that growers have a better idea of yield potential and pending favorable seasonal conditions before applying the N. [30]

Budgeting

The critical factor in budgeting is the target yield, and protein as crop yield potential is the major driver of N requirement. As a guide, Table 4 shows the N required for different yield and protein combinations at maturity and anthesis. For example, if you are targeting a 3 t/ha crop at 11% protein you would need to have about 62 kg N/ha taken up by the crop by flowering. The amount of fertiliser N required will depend on your estimate of fertiliser recovery, but if you work on a 50% recovery, you would need to supply 124 kg N/ha.

Clearly, predicting yield during the growing season is crucial to allow growers to make tactical decisions on N management. Recent experience in the mid-North of South Australia has shown that Yield Prophet® can predict yields accurately in mid-August and can assist with N decisions. Other tools, such as the PIRSA-CSIRO N calculator, provide a way of calculating N budgets and estimating N requirements. [31]

Table 4: *N requirements for cereal crops at different combinations of yield and grain protein at maturity and the corresponding N required at anthesis. The estimates are based on the assumption that 75% of the total crop N is in the grain at maturity and that 80% of the total N is taken up by anthesis.*

Grain Yield (t/ha)	Growth Stage	Grain Protein(%) 9	10	11	12	13
		(kgN/ha)				
1	Maturity	21	23	26	28	30
	Anthesis	17	19	21	22	24
2	Maturity	42	47	51	56	61
	Anthesis	34	37	41	45	49
3	Maturity	63	70	77	84	91
	Anthesis	51	56	62	67	73
4	Maturity	84	94	103	112	122
	Anthesis	67	75	82	90	97
5	Maturity	105	117	129	140	152
	Anthesis	84	94	103	112	122
6	Maturity	126	140	154	168	182
	Anthesis	101	112	124	135	146

Source: GRDC

30 R Quinlan, A Wherrett (2013) Nitrogen—NSW, http://www.soilquality.org.au/factsheets/N-nsw

31 G McDonald, P Hooper P (2013) Nitrogen decision—Guidelines and rules of thumb, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/N-decision-Guidelines-and-rules-of-thumb

5.6 Phosphorus

Key Points

- Phosphorus (P) is one of the most critical and limiting nutrients in agriculture in Australia.
- P cycling in soils is complex.
- Only 5–30% of P applied as fertiliser is taken up by the plant in the year of application.
- P fertiliser is best applied at seeding.

Phosphorus (P) is an essential nutrient required for the growth of wheat with a key role in the structure of cell membranes, DNA and RNA, photosynthesis and respiration. Early plant growth is particularly dependent on adequate P due to its role in cell division. [32] Phosphorus is important in growing tissue where cells are actively dividing, i.e. seedling root development, flowering and seed formation. There must be sufficient plant-available N to get a response to P and there must be sufficient P for S and/or K responses to occur. Additive effects of N and P appear to account for most of the above-ground growth and yield response. [33] The symptoms of P deficiency are particularly evident during early growth stages. Mild P deficiency causes stunting while severe deficiency darkens leaves, causes older leaves to brown and die off and reduces tillering, head and grain numbers and slows crop development.

Soil testing should be conducted to determine phosphorus status. The phosphorus cycle in soil and plants is shown in Figure 2.

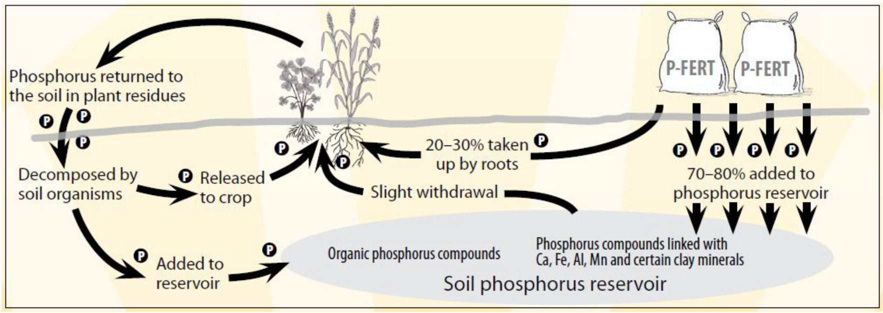

Figure 2: *The P cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited.*

From the Fertiliser Industry Federation of Australia Inc., 2000.

Source: Soilquality.org

In many soils of south-eastern Australia, P application has good residual value. However, if not applied for five to 10 years, even those soils with excellent fertiliser history are likely to develop a P deficiency.

In sandy soils P has a tendency to leach out of the soil. Sandy soils have been measured to lose up to 100% of applied P to leaching in the first season. Certainly 50% losses are common. Soils with sufficient levels of "reactive" iron (Fe) and aluminium (Al) will tend to resist P leaching. If you have sandy soils with low reactive levels of Fe and Al then you should test your P levels and apply less P more often, so that you don't lose your expensive P dollar to leaching. In soils with high free lime (10–20%), P will react with calcium carbonate in the soil to create insoluble calcium phosphates. Lock-up of P occurs on these soils at high pH and more sophisticated methods of applying P may be needed.

VIDEOS

Watch: GCTV13: Phosphorus uptake

MORE INFORMATION

Phosphorus as a nutrient for wheat in Southern Australia

32 CropPro Phosphorus as a nutrient for wheat in southern Australia. http://www.croppro.com.au/resources/Review%20-%20Phosphorus%20for%20wheat.pdf

33 D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers. Grains Research and Development Corporation, March 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs

5.6.1 Symptoms of phosphorus deficiency

Phosphorus deficiency is difficult to detect visually in many field crops, as the whole plant tends to be affected. Stunted growth, leaf distortion, chlorotic areas and delayed maturity are all indicators of phosphorus deficiency. Phosphorus is concentrated at the growth tip, resulting in deficient areas visible first on lower parts of the plant. A purple or reddish colour associated with accumulation of sugar, is often seen in deficient plants, especially when temperatures are low. Deficient cereal crops are often poorly tillered. Visual symptoms, other than stunted growth and reduced yield are not as clear as are those for N and K deficiencies. At some growth stages, P deficiency may cause the crop to look darker green. [34]

Paddock:

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header (Photo 3).
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf diseases.

Photo 3: *P deficient plants on the left are later maturing with fewer smaller heads.*

Source: DAFWA

Plant:

- In early development, usually in cases of induced P deficiency, seedlings appear to be pale olive green and wilted (Photo 4).
- On older leaves, chlorosis starts at the tip and moves down the leaf on a front, while the base of the leaf and the rest of the plant remains dark green. Unlike N deficiency, necrosis (death) of these chlorotic (pale) areas is fairly rapid, with the tip becoming orange to dark brown and shrivelling, while the remainder

34 R Quinlan, A Wherret. (2016). Phosphorus – Western Australia. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/phosphorus

turns yellow. At this stage the second leaf has taken on the early symptoms of P deficiency.

- By tillering, (uncommon) symptoms of severe deficiency are dull dark green leaves with slight mottling of the oldest leaf. [35]

Photo 4: *Stunted growth and yellowing of leaf tips in P deficient wheat (right).*

Source: Soil Quality Pty Ltd

5.6.2 Managing phosphorus

Key points

- After decades of consistent P application south eastern Australian soils, many soils now have adequate P status.
- Before deciding on a fertiliser strategy, use soil testing to gain a thorough understanding of the nutrient status across the farm.
- If the soil P status is sufficient, there may be an opportunity for growers to save money on P fertiliser by cutting back to a maintenance rate.
- Consider other factors: if pH ($CaCl_2$) is less than 4.5, the soil is water repellent or root disease levels are high, then the availability of soil test P is reduced and a yield increase to fertiliser P can occur even when the soil test P results are adequate.
- Work with an adviser to refine your fertiliser strategy.
- P reserves have been run down over several decades of cropping.
- Adding fertiliser to the topsoil in systems that rely on stored moisture does not always place nutrients where crop needs them.
- Testing subsoil (10–30 cm) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Applying P at depth (15–20 cm deep on 50 cm bands) can improve yields over a number of cropping seasons (if other nutrients are not limiting).
- Addressing low P levels will usually increase potential crop yields, so match the application of other essential nutrients, particularly N, to this adjusted yield potential. [36]

35 DAFWA (2015) Diagnosing phosphorus deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1996

36 GRDC (2012) Crop nutrition: Phosphorus management—Southern region Factsheet, www.grdc.com.au/GRDC-FS-PhosphorusManagement

MORE INFORMATION

Phosphorus in the South East Soils.

Crop nutrition: Phosphorus management – Southern region Factsheet

VIDEOS

WATCH: GCTV13: Phosphorus deficiency.

WATCH : Improving phosphate use efficiency

- Only 5–30 % of P applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus does not move readily in soils except in very light sandy soils in high rainfall areas. [37]

Long fallows due to crop rotation or drought may accentuate P deficiency through absence of mycorrhizae. Phosphorus fertiliser should be used in this situation. Where needed, apply P with the seed at planting. [38]

Place phosphorous with or near the seed at seeding time or band prior to seeding. High application rates can lead to both salt burning of the seedlings and a thin plant stand, reducing potential yield. [39]

Growers are encouraged to continue using starter P fertilisers at rates appropriate for the crop row spacing and soil moisture conditions at sowing. Applying small amounts of P in the seed row at sowing is offering excellent utilisation of the nutrient by the emerging crop. Yield increases with deep P application are dependent on a crops' ability to access and utilise the nutrient in the band. [40]

Soil testing

Testing of the P levels in your soil is important and will help in the budgeting of your P dollar.

Phosphorus is relatively immobile in soils and P applied to the 0 to 10 cm layer generally remains in that layer, especially in no-till systems. In most of our cropping systems, the Colwell-P soil test is still the benchmark soil P test used in Australia. The critical values differ between soil types, and the values given are expressed for the major soil types in south-eastern Australia. Soil critical P test value is not affected by wheat yield except where yields are very low (less than one tonne per hectare). On the highly calcareous soils (calcarosols), the DGT-P soil test provides a better prediction of crop response to fertiliser than Colwell-P. [41]

The release of P is related to:

- The total amount of P in the soil.
- The abundance of iron and aluminium oxides.
- Organic carbon content.
- Free Lime/ Soluble Calcium Carbonate.
- P Buffer Index (PBI).

Available P tests like the Colwell and Olsen's P test don't measure available P. Rather, they express an indication of the rate at which P may be extracted from the soils. This indicator of rate is calibrated with field trials. There is a relationship between Total Soil P and Colwell P and this can enable you to predict when a given level of P input (fertiliser) or output (product removal) will result in a risk of P rate of supply becoming a limiting factor. [42]

Sulfur

Sulfur (S) is an essential nutrient required for the growth of wheat and is a key element in the amino acids that form proteins essential for cellular structure and enzymes. Sulfur is also an essential part of proteins needed for pasta-making quality durum. The essential role of S in the formation of grain protein leads to grain protein being low when S is deficient.

37 R Quinlan, A Wherret. Phosphorus – Western Australia. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/phosphorus

38 DAFQ (2012) Durum wheat in Queensland. Queensland Department of Agriculture and Fisheries, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

39 Alberta Government (2016) Fall Rye Production, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

40 DW Lester, M Bell, R Graham, D Sands, G Brooke (2016) Phosphorus and potassium nutrition. GRDC Update Papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Phosphorus-and-potassium-nutrition

41 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

42 G Bailey, T Brooksby. Phosphorus in the South East Soils. Natural resources South East. Government of South Australia.

5.6.3 Symptoms of sulfur deficiency

Vegetative symptoms of S deficiency are stunting, yellowing of the whole plant and severe yellowing of the younger leaves when S deficiency is persistent. [43]

Paddock:

- Areas of pale or stunted plants (Photo 5).

Photo 5: *Areas of pale plants characterise Sulfur deficiency (NOTE: many other nutrient deficiencies also exhibit pale patches).*

Source: DAFWA

Plant:

- Plants grow poorly, lack vigour with reduced tillering, delayed maturity and lower yields and protein levels.
- Youngest leaves are affected first and most severely.
- Leaves on deficient plants leaves turn pale with no stripes or green veins but generally do not die and growth is retarded and maturity delayed (Photo 6).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red. [44]

43 CropPro (2013) Sulfur as a nutrient for agricultural crops in southern Australia. http://www.croppro.com.au/resources/Review%20Sulfur%2026082013.pdf

44 DAFWA (2015) Diagnosing sulfur deficiency in cereals. Department of Agriculture and Food Western Australia, July 2015, https://agric.wa.gov.au/n/1998

Photo 6: *Sulfur deficient wheat.*

Source: International Plant Nutrition Institute

Most soil S is in an organic form and not directly accessible to plants until undergoing mineralisation by micro-organisms. The rates of mineralisation and immobilisation are determined by soil water, temperature, pH and availability of other nutrients. As such, available S varies throughout the year with more mineralisation or organic S during warm, moist conditions and less during dry, waterlogged or cold conditions. Soils deficient in S are historically dominated by pasture production; namely Gippsland in Victoria, the tablelands in New South Wales, coastal regions with higher rainfall in SA, and northern coastal regions of Tasmania. [45]

Managing sulfur

Top-dressing 10–15 kilograms per hectare of S as gypsum or ammonium sulphate will overcome deficiency symptoms. [46]

Foliar sprays generally cannot supply enough S for plant needs. [47]

Historically, S has been adequate for crop growth because it is supplied in superphosphate, in rainfall in coastal areas and some from gypsum. In the southern region sulfur-responsive soils are uncommon in cereals. Sulfur inputs to cropping systems have declined with the use of triple superphosphate (TSP), mono-amomonium phosphate (MAP) and di-ammonium phosphate (DAP) which are low in S. Sulfur is also subject to leaching and in wet seasons may move beyond the root zone. Occurrence of S deficiency appears to be a complex interaction between the mineralisation of S from soil organic matter, seasonal conditions, crop species and plant availability of subsoil S. Similar to N, these factors impact on the ability of the soil S test to predict plant available S. Interrogation of wheat trial data in the GRDC's 'Making better fertiliser decisions for cropping systems in Australia' project database found that the critical soil S test value (measured in the 0 to 10 cm soil layer) is poorly defined when considered across all soil types. [48]

45 CropPro (2013). Sulfur as a nutrient for agricultural crops in southern Australia. http://www.croppro.com.au/resources/Review%20Sulfur%2026082013.pdf

46 DAFWA (2015) Diagnosing sulfur deficiency in cereals. Department of Agriculture and Food Western Australia, July 2015, https://agric.wa.gov.au/n/1998

47 DAFWA. Diagnosing Sulfur deficiency in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-sulfur-deficiency-cereals

48 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

5.7 Potassium

Key points:

- Soil testing combined with plant tissue testing is the most effective means of determining Potassium (K) requirements.
- Banding away from the seed, at or within 4 weeks of sowing, is the most effective way to apply K when the requirement is less than 15 kg/ha.
- Sandy soils in high rainfall areas are prone to K deficiency.
- Soil testing is the most effective means of determining K requirements.
- Deficiency symptoms first occur in the older leaves, and can be mistaken for disease infections.
- Potassium export during harvest must be accounted for when calculating nutrient budgets.

Potassium (K) is one of the essential nutrients in plants. It has many functions including the regulation of the opening and closing of stomata, which are the breathing holes found on plant leaves and therefore regulate moisture loss from the plant.

Generally, in the southern region cropping soils are unresponsive to additions of K. However, as crops continue to mine K from soils, this may change in the future. Potassium deficiency is more likely to occur on light soils and with high rainfall, especially where hay is cut and removed regularly. Factors such as soil acidity, soil compaction and waterlogging will modify root growth and the ability of crops to extract subsoil K. The critical values for Colwell-K in wheat vary with soil type from about 40 mg/kg on chromosols, to about 49 mg/kg on kandosols and about 64 mg/kg on brown ferrosols. There is some evidence that critical values increased with increasing crop yield and on soils with no acidity constraints to root growth. [49]

5.7.1 Symptoms of potassium deficiency

Potassium is highly mobile in the phloem and can be moved to newer leaves if the nutrient is in short supply, with deficiency symptoms appearing first on older leaves. [50]

Paddock:

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows (Photo 7).
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease. [51]

49 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

50 R Quinlan, A Wherret. (2016). Potassium. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/potassium

51 DAFWA (2015) Diagnosing potassium deficiency in wheat. Department of Agriculture and Food Western Australia, April 2015, https://agric.wa.gov.au/n/1997

Photo 7: *Header rows have fewer potassium deficiency symptoms.*

Source: DAFWA

Plant:

- Plants appear paler and weak.
- Older leaves are affected first with leaf tip death and progressive yellowing and death down from the leaf tip and edges. There is a marked contrast in colour between yellow leaf margins and the green centre (Photo 8).
- Yellowing leaf tip and leaf margins sometimes generates a characteristic green 'arrow' shape towards leaf tip. [52]

52 DAFWA (2015) Diagnosing potassium deficiency in wheat. Department of Agriculture and Food Western Australia, April 2015, https://agric.wa.gov.au/n/1997

Photo 8: *Plants affected by K deficiency may be paler, weaker and more susceptible to leaf disease. Discouloured leaf tissue can be bright yellow.*

Source: Department of Agriculture and Food Western Australia

5.7.2 Managing potassium

Top-dressing K will generally correct the deficiency. Foliar sprays generally cannot supply enough K to overcome a severe deficiency and can also scorch crops. [53]

Banded K has been shown to be twice as accessible to the crop as top-dressed K. This is thought to be related to improved availability for the emerging crop, and decreased availability for weeds. Growers should not band high rates (i.e. >15 kg/ha) particularly with sensitive crops and should try to place K fertilisers away from the seed. Furthermore, growers should be aware that nutrient auditing requires fertiliser applications to cover K export during harvest, and are encouraged to account for variations in yield where possible.

If a paddock is severely deficient then K needs to be applied early in the season to maximise response to the application. At seeding or up to four weeks after will optimise the benefits of K application. [54]

Assessing potassium requirements

Soil and plant tissue analysis together give insight into the availability of K in the soil. Growers should not rely on soil testing alone as results are subject to many potential sources of error.

53 DAFWA. Diagnosing potassium deficiency in wheat, https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-wheat

54 R Quinlan, A Wherret. Potassium. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/potassium

Tissue analysis of whole tops of crop plants will determine whether a deficiency exists but doesn't define a K requirement. These results are generally too late to be useful in the current season, but inform the need to assess K requirements for the next crop.

K available in the soil is measured by the Colwell K or Exchangeable K soil tests. The amount of K needed for plant nutrition depends on soil texture (Table 5).

Table 5: *Critical (Colwell) soil test thresholds for K (ppm).*

	Deficient	Moderate	Sufficient
Cereal, canola, lupins etc. (Brennan & Bell 2013)	< 50	50–70	> 70
Pasture legumes (Gourley et al. 2007)	< 100 (sand) <150 (clay loam)	100-140 (sand) 150-180 (clay loam)	> 140 (sand) > 180 (clay loam)

Source: Soilquality.org

Sandy soils require less K to be present, but are more likely to show deficiencies. Clay soils require more K to be present, but are more capable of supplying replacement K through the weathering of clay minerals.

K lost through product removal should be replaced once paddocks fall below sufficient K levels, rather than waiting for deficiency symptoms to appear. Replacement requirements for each crop differ, and this must be accounted for when budgeting K requirements for the coming season.

Fertiliser types

Sulphate of potash (SOP—potassium sulphate) is usually recommended if K is deficient. Applying the cheaper muriate of potash (MOP—potassium chloride) also corrects K deficiency, but it also adds chloride to the soil, which contributes to overall salinity and can decrease the establishment of seedlings.

Potassium magnesium sulphate can also be used where magnesium and sulphate are also required. This form is often used in "complete" fertiliser blends. Potassium nitrate supplies N and K in a highly water soluble (and available) form, but is rarely used in broadacre farming because of its cost.

Fertiliser placement and timing

K generally stays very close to where it is placed in the soil. Banded K has been shown to be twice as accessible to the crop as top-dressed K. This is thought to be related to improved availability for the emerging crop, and decreased availability for weeds. Seed must be sown within 50 mm of the K drill row or seedlings may miss the higher levels of K. If a paddock is severely deficient then K needs to be applied early in the season, at seeding or up to 4 weeks after. [55]

5.8 Micronutrients

Key points:

- Micronutrients or trace elements most likely to be out of balance in southern Australian durum cropping soils are zinc, copper and manganese.
- Trace elements are important in particular situations but are not miracle workers.
- Deficiencies are not uncommon, but when they occur can give large yield penalties.

55 Soilquality.org. Potassium—NSW, http://www.soilquality.org.au/factsheets/potassium-nsw

- Diagnosis by soil test and tissue test is difficult, but in most cases, the potential for deficiencies can be assessed by reviewing soil types, crop type and seasonal conditions.
- Products vary in their efficiency and growers should look for evidence for the efficacy of products in their region.

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

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

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

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

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

There is increasing concern in some districts that trace element deficiencies may be the next nutritional barrier to improving productivity. This is because current cropping systems are exporting more nutrients to the grain terminal than ever before. [56]

Most growers and agronomists are fully aware of the nitrogen and phosphorus demands of crops, and meeting those demands is a major investment in crop production. Sulfur and potassium are also important in some regions as are calcium and magnesium. These six nutrients, the macronutrients, are complemented by a set of nutrients required in smaller amounts; the micronutrients or trace elements. Even though needed in small quantities, Copper (Cu), Manganese (Mn), Iron (Fe), Zinc (Zn), Boron (B) and Molybdenum (Mo) are all essential for plant growth, although the demand is small relative to nitrogen and phosphorus.

South Australia has a long history of micronutrient research, and in the early 1960s it was found that foliar sprays of Mn onto barley gave a 20-fold yield response in the southern Yorke Pennisula. This was the first time foliar trace elements had been applied to agricultural crops in Australia. Similarly, with copper, South Australian scientists have led the way with diagnosis and remediation, as well as developing a deep understanding of cultivar differences in copper (and manganese) responses. Even so, between farms and within farms, the response to micronutrients will differ. [57]

5.8.1 Zinc

Compared to bread wheats, durum wheats can be sensitive to low zinc (Zn) levels. Crops usually tolerate low Zn levels when grown on heavy, self-mulching black earths (pHCa 8–8.5). Elongated necrotic lesions (dead patches) on the lower leaves may indicate the onset of Zn deficiency. When a crop is growing in a very wet, high-phosphate soil for several weeks, Zn deficiency symptoms may be evident. [58]

MORE INFORMATION

GRDC Update Papers: Detecting and managing trace element deficiencies in crops.

GRDC Update Papers: Trace elements; copper and manganese – their role, requirements and options.

Trace element disorders in South Australian Agriculture

56 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Detecting-and-managing-trace-element-deficiencies-in-crops

57 Norton R. (2014). GRDC Update Papers: Trace elements; copper and manganese – their role, requirements and options. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Trace-elements-copper-and-manganese-their-role-requirements-and-options

58 Hare R. (2006). Agronomy of the durum wheats Kamilaroi⊕, Yallaroi⊕, Wollaroi⊕ and EGA Bellaroi⊕. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

Symptoms of zinc deficiency

Paddock:

- Patchy growth of stunted plants with short thin stems and usually pale green leaves.
- Heavily limed soils, sands and gravels or alkaline grey clays tend to be most affected.
- Zinc deficiency symptoms are usually seen on young seedlings early during the growing season.

Plant:

- Young to middle leaves develop yellow patches between the mid-vein and edge of the leaf and extend lengthways towards the tip and base of the leaf. This stripe may occur only on one side of the mid-vein.
- The areas eventually die turning pale grey or brown.
- The leaf changes from green to a muddy greyish-green in the central areas of middle leaves.
- Stunted plants often have 'diesel-soaked' leaves, showing dead areas about halfway along the leaves, causing them to bend and collapse in the middle section (Photo 9).
- Maturity is delayed. [59]

Photo 9: *Plants affected by Zn deficiency may show necrosis half way along middle and older leaves, causing them to droop.*

Source: Department of Agriculture and Food Western Australia

59 DAFWA (2015) Diagnosing zinc deficiency in wheat. Department of Agriculture and Food Western Australia, June 2015, https://agric.wa.gov.au/n/1999

Management strategies

If the soil is known to be low in Zn (soil and plant tissue tests are available), a 1% aqueous solution of zinc sulfate heptahydrate applied as a foliar spray two to four weeks after emergence ameliorates the deficiency at about 1 kg/ha. Zinc sulfate monohydrate applications can provide 4–5 years supply of this essential micronutrient. Apply at 15 kg/ha on sandy and sandy-loam soils, or 30 kg/ha for clay and clay-loam soils and incorporate some months before sowing. Where P fertilisers are required, products that are coated with Zn provide a very efficient method of increasing crop recovery of applied Zn. Note that zinc oxide (5 kg Zn/ha) applications can be spread with N fertilisers but not with P fertilisers, as the P can bind with the Zn and render it unavailable. A range of zinc-fortified starter fertilisers are also available. [60]

- Zinc can be applied via foliar spray (effective only in current season) or drilled soil fertiliser.
- Zinc foliar sprays need to be applied as soon as deficiency is detected to avoid irreversible damage.
- As Zn is immobile in the soil, topdressing is ineffective, only being available to the plant when the topsoil is wet.
- Mixing Zn throughout the topsoil improves availability due to more uniform nutrient distribution.
- Zinc drilled deep increases the chances of roots being able to obtain enough Zn when the topsoil is dry.
- Zinc seed treatment is used to promote early growth where root disease is a problem, but the level is lower than a plant needs in the current season.
- Zinc present in compound fertilisers often meets the current requirements of the crop.

5.8.2 Copper

Copper (Cu) is essential for pollen formation and has a role in formation of chlorophyll and lignification (cell wall strength). Deficiency causes sterile pollen which, in turn, causes poor grain formation and high yield losses. [61]

Symptoms of copper deficiency

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.

Plant:

- Youngest growth is affected first.
- First sign of Cu deficiency before flowering is growing point death and tip withering, and/or bleaching and twisting up to half the length of young leaves (Photo 10).
- Base of the leaf can remain green.
- Old leaves remain green, but paler than normal.
- Tiller production may increase but die prematurely.
- Mature plants are dull grey-black in colour with white or stained empty or 'rat-tail' heads.

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60 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

61 DAFWA (2015) Diagnosing copper deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1990

- Grain in less severely affected plants may be shrivelled. Heads with full grain droop due to weak stems. [62]

Photo 10: *Plants affected by Cu deficiency may have partly sterile heads and twisted flag leaves.*

Source: Department of Agriculture and Food Western Australia

Managing copper

- Copper can be applied as a foliar spray (only effective in the current season) or drilled soil fertiliser.
- Copper foliar sprays are not effective after flowering as sufficient Cu is required pre-flowering for pollen development.
- Mixing Cu throughout the topsoil improves availability due to more uniform nutrient distribution.
- As Cu is immobile in the soil, topdressing is ineffective, only being available to the plant when the topsoil is wet.
- In long term no-till paddocks frequent small applications of Cu via drilled or in-furrow application reduces the risk of plant roots not being able to obtain the nutrient in dry seasons.
- Copper drilled deep increases the chances of roots being able to obtain enough copper when the topsoil is dry.
- Copper seed treatment is insufficient to for plant requirement in the current season. [63]

5.8.3 Boron

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

62 DAFWA (2015) Diagnosing copper deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1990

63 DAFWA (2015) Diagnosing copper deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1990

Symptoms of boron deficiency

Paddock:

- Sandier, more acidic parts of the paddock will be most affected.

Plant:

- Symptoms appear first on the youngest leaf and gradually spread to older growth.
- First sign of boron (B) deficiency is leaf splitting close to the mid rib accompanied by saw tooth notches along the leaf edge (Photo 11).
- In severe cases tillering increases, shoots wither and new leaves die back from tip. [64]

Photo 11: *Plants affected by B deficiency may show saw tooth notches on leaf edge (left) and withering of emerging shoot (right).*

Source: Department of Agriculture and Food Western Australia

Boron toxicity

Boron toxicity is usually an inherent feature of a soil and is a particular problem when high boron levels occur in the subsoil.

What to look for:

Paddock:

Symptoms mostly occur in spring and are identical to those in drought affected plants.

Plant:

Symptoms appear first and most severely on the oldest leaves.

Leaf tip death progressing from the tip and margins.

In severe cases, yellow spotting occurs lower down on older leaves.

Managing boron

- Boron can be applied via soil or foliar applications of B.

64 DAFWA (2015) Diagnosing boron deficiency in wheat. Department of Agriculture and Food Western Australia, April 2015, https://agric.wa.gov.au/n/1988

- Soil applications generally last longer but can be leached from acidic, sandy soils. Avoid using higher rates than necessary as these can cause B toxicity in plants.
- Foliar applications act rapidly but timing of application is important to avoid irreversible damage. [65]

IN FOCUS

Nutrient uptake and distribution by bread and durum wheat under drought conditions in SA

An important limitation to the production of durum wheat in SA is its poor adaptation to the alkaline, sodic soils of the cereal belt, which often results in nutrient imbalances in the crop. A field experiment was conducted at Palmer, SA, to measure the nutrient uptake and distribution between grain and straw of three bread wheat cultivars and nine cultivars and breeding lines of durum wheat. The purpose of the work was to characterise the patterns of nutrient uptake and to examine whether there were major, consistent differences between bread wheat and durum wheat. Rainfall during the growing season was below average and the crops suffered from drought stress after anthesis. Plants were marginally deficient or deficient in N, P and Zn, and B concentrations were high. Compared with bread wheat, durum wheat had a very much higher concentration of sodium (Na), higher concentrations of calcium (Ca) and S, but lower concentrations of K, magnesium (Mg), manganese (Mn) and Cu. Total amounts of P, Zn and Na in the shoot continued to increase throughout the growing season with significant increases occurring during grain filling, whereas there was little increase in the amount of N, K, B and Mn during grain filling. The maximum rate of nutrient uptake occurred before the time of maximum crop growth rate, and was in the order K (10.1 weeks after sowing), N (10.6), P (11.3), Mn (12.0), Zn (12.5) and B (14.6); maximum growth rate occurred at 14.8 weeks. There was no consistent difference between bread and durum wheat in the partitioning of nutrients to the grain. The importance of N and Zn uptake to the growth of the durum wheat genotypes was shown by significant correlations between maximum uptake rates of these nutrients and maximum crop growth rate, with the strongest correlation being with Zn. Growth rate was not correlated with uptake rates of other nutrients.
A number of genotypes of durum wheat had maximum rates of Zn and Mn accumulation up to twice those of the current commercial genotypes. Some of these lines have yielded well at Zn- and Mn-deficient sites which indicates that the micronutrient efficiency of durum can be improved.
Late in the season the experiment showed signs of infection by crown rot (*Fusarium graminearum* Schw. Group 1). Durum wheat showed more severe symptoms than bread wheat and the number of white heads in durum wheat was inversely correlated with the concentration of Zn in the shoot during the pre-anthesis period. [66]

65 DAFWA (2015) Diagnosing boron deficiency in wheat. Department of Agriculture and Food Western Australia, April 2015, https://agric.wa.gov.au/n/1988

66 A Zubaidi, GK McDonald, GJ Hollamby (1999). Nutrient uptake and distribution by bread and durum wheat under drought conditions in South Australia. Animal Production Science, 39(6), 721–732, http://www.publish.csiro.au/paper/EA98185.htm

5.9 Paddock nutrition

It is not uncommon for paddocks to have multiple nutrition deficiencies, or variations in nutritional requirements, even with a similar cropping history. Paddock history, past crop performance, fertiliser test strips and soil tests can help to determine the most appropriate decision about subsequent crop management. Fertiliser is a major cost. Fertiliser rates to meet crop requirements may be modified if residual fertiliser from the last season remains.