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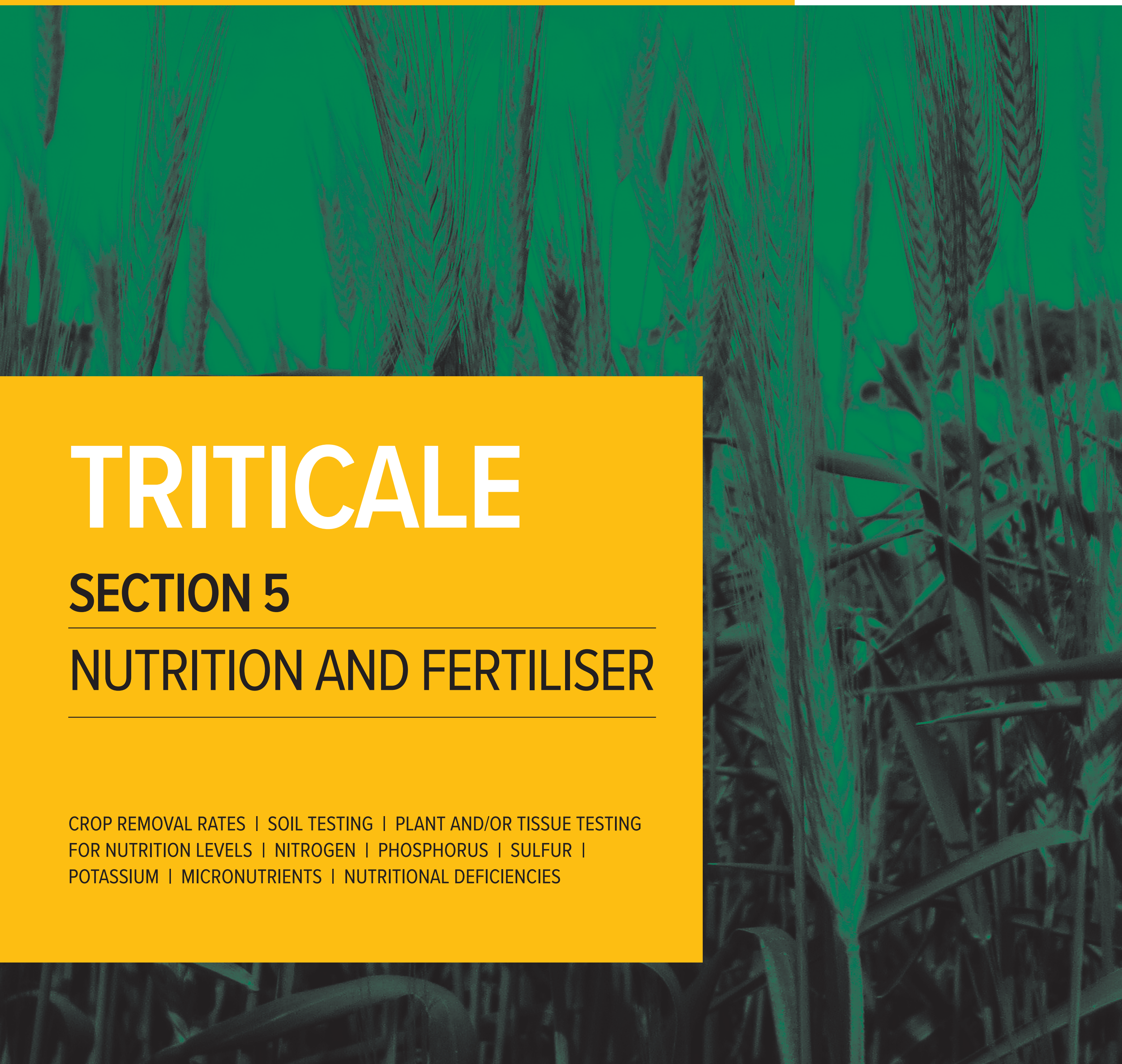

TRITICALE

SECTION 5

NUTRITION AND FERTILISER

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

Nutrition and fertiliser

Key messages

- In nutrient deficient soils, triticale appears to respond better to applied fertilisers than other cereals. Triticale has the capacity to survive by utilising trace elements in soils which would be considered nutrient deficient for any other type of crop. However, growth and yield of triticale is very responsive to phosphorus and nitrogen. [1]
- Triticale has higher nutrient uptake efficiency than other crops. [2]
- The nutrition requirements of triticale are similar to wheat. Triticale is very responsive to high inputs of seed and fertiliser. Adequate fertiliser is needed to achieve protein levels above 10%. [3]
- Triticale has similar phosphorus and nitrogen requirements as wheat and responds to most compound fertilisers.
- In southern Australia high rates of fertiliser applied to triticale on sandy country have resulted in increased yields. [4]
- Most soils in Western Australia (WA) are naturally deficient in the trace elements copper (Cu), zinc (Zn), manganese (Mn) and molybdenum (Mo).
- Triticale grows productively on alkaline soils where certain trace elements are deficient for other cereals. [5]

Triticale has a very extensive root system and can mine the soil more efficiently in conditions where fertility is poor (Photo 1). In general, triticale will respond favourable to cultural practices commonly used for the parental species wheat. However, it has been found that grain biomass and yield response of triticale are substantially higher under larger increments of nitrogen and phosphorus inputs. [6]

High yields in any crop are strongly dependent on adequate nutrients being available during growth.

1 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

2 Mergoum *et al*. 2004 – in Tshewang S. (2011). Frost tolerance in Triticale and other winter cereals at flowering. https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

3 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

4 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

5 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

6 Tshewang S. (2011). Frost tolerance in Triticale and other winter cereals at flowering. https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

Photo 1: *Above and below ground growth showing extensive root system.*

Source: Veg trials.

5.1.1 Declining soil fertility

The natural fertility of cropped agricultural soils is declining over time (Photo 2). Grain growers must continually review their management programs to ensure the long-term sustainability of high-quality grain production. Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils.

Paddock records, including yield and protein levels, fertiliser test strips, crop monitoring, and soil and plant tissue tests all assist in the formulation of an efficient cropping program. Although crop rotations with grain legumes and ley pastures play an important role in maintaining and improving soil fertility, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed.

The yield potential of a crop will be limited by any nutrient the soil cannot adequately supply. Poor crop response to one nutrient is often linked to a deficiency in another nutrient. Sometimes, poor crop response can also be linked to acidity, sodicity or salinity, pathogens, or a lack of beneficial soil microorganisms. [7]

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

Photo 2: *Cereal plants growing in paddock with low soil fertility.*

Source: FAO

Balancing nutrition

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

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. [8]

5.1.2 Fertilisers

Successful fertiliser decisions require robust information about a crop's likely yield response to applied fertiliser in a specific soil type, paddock history and season.

Triticale has similar phosphorus and nitrogen requirements as wheat and responds to most compound fertilisers. As with most crops, rates of fertiliser application should be based on soil testing and other historical response information as well as anticipated costs and returns.

It is also valuable to know the anticipated market for the grain and whether price gradients may reward higher protein levels. This may warrant extra nitrogen usage. [9]

Trials in NSW tested the response of triticale varieties to N and P application. Soil tests indicated marked differences between the years in nitrogen (N) and phosphorus (P) status. In 2002 the site had a very low soil N level (2ug/g nitrate) and a low/medium level of P (16ug/g available P). The data from the 2004 site indicated much higher levels of nutrients, being 64ug/g nitrate and 46ug/g phosphorus.

Although this experiment in 2004 used varieties that have now been largely superseded, the major findings from these experiments were that in a high rainfall region with yield potential levels above average the yield responses to N fertiliser of a range of triticale varieties was at least equal to those for wheat (Table 1). With high yield potential (up to 8 t/ha) triticale varieties showed up to 4 times the yield response of the wheat variety Janz. At lower yields levels (2 t/ha) there were no differences in response between wheat and triticale varieties.

Table 1: *Response of triticale (tonne/ha) to nitrogen fertiliser.*

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 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

Variety	0 nitrogen	50 kg/ha nitrogen	100 kg/ha nitrogen	Response 100 kg/ha nitrogen
Everest	6.85	7.96	7.98	1.13
Kosciusko	7.37	7.48	8.34	0.97
Tahara	7.96	8.22	8.52	0.56
Janz wheat	6.73	6.99	7.00	0.27

These results indicated that, with low/medium yield expectations, wheat and triticale appear to show similar responses to additional N fertiliser. In locations with increased yield potential there is a suggestion that N requirements of triticale varieties exceed those of bread wheat varieties. The exact amounts of additional N fertiliser applied will depend on expected grain yields, soil N status, crop water availability and the current ratio of N fertiliser prices and crop returns.

Growers need to aim for sufficient soil N to obtain 11.5% protein in triticale as below this level both grain yield and protein will be reduced. This aspect of triticale has been overlooked in the past and often triticale yields have been severely reduced compared with those in wheat as a result of inadequate N fertiliser application. [10]

A productive triticale will require application of phosphorous (P) and nitrogen (N) at sowing. Additional nitrogen is likely to be required for maximum dry matter production for grazing and grain yield, particularly if the crop has been grazed. Consider applying 15—20 kg P per ha at sowing. This is equivalent to 75—100 kg MAP per ha which will also include 7.5—10 kg N per ha. A triticale used for grazing as well as grain production will require significant N. If targeting 3 t per ha then a minimum of 69 kg N per ha should be applied just to cover removal. If grazing is also included or soil nitrogen levels are low, additional N should be applied. Application can be split between sowing and top-dressing post-grazing or during stem elongation stage (soon after Zadoks 31).

Paddocks with a history of legume dominant pasture or a pulse crop (e.g. lupins, field peas) tend to have a higher N status than those with a history of grassy pasture or cereal and canola crops and will not need as much applied N. [11]

Table 2 lists the concentration of nitrogen and phosphorous in common fertilisers. Use this to calculate total quantity of fertiliser to apply. In the example with a requirement of 69 kg N per ha this could be achieved by applying:

- 100 kg MAP per ha or 10 kg N per ha, plus
- 130 kg urea per ha or 59.8 kg N per ha supplying a total of 69 kg N per ha for the season.

10 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

11 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

Table 2: *Nitrogen and phosphorous content of common high analysis fertilisers.*

Product	Phosphorus		Nitrogen	
	Kg/kg product	Kg/100 kg product	Kg/kg product	Kg/100 kg product
MAP	2.2	22	1.0	10
DAP	2.0	20	1.8	18
Urea	0	0	4.6	46

Source: Waratah Seed Co

MORE INFORMATION

Fertilising for grazing cereals

Crop Nutrition: region by region

In a field experiment conducted in India, nine combinations of nitrogen (N) and phosphorus (P) were factorially randomised with four triticales and one check each of wheat and rye to investigate the effect of progressive rates of application (180–300 kg N+P ha^{-1}) of combined N+P fertiliser on grain yield and quality. Grain yield, protein content, and values for yield components significantly increased with increasing combined N+P fertiliser rates up to 240 kg N+P ha^{-1} (200 kg N+40 kg P ha^{-1}). The response of further increases in N+P rates gradually diminished, thereafter, despite increasing N and/or P in the fertiliser combinations. This research revealed the harmful effects of overfertilisation. This was thought to be due to a decrease in the activity of the enzyme despite increasing N and/or P in the fertiliser combinations. [12]

Application

Stage: Pre Plant (or) At Planting

Rate: 250–400 kg/Ha (Dryland), 500–750 kg/Ha (Irrigated)

Product: Standard Pellets, Organic Complete (or) Growers Special

Application Method

Apply by using either gravity feed openers or air drills to sub-surface band the fertiliser 5 cm (2") below or to the side of the seed.

Application Considerations

Use higher rates where nitrogen is known to be deficient, when double cropping or with large amounts of undecomposed stubble.

Rates should be reduced by 50% for very sandy soils and may be increased by 30% for heavy textured soils or where soil moisture conditions at planting are excellent.

Rates should be reduced by 50% when planting equipment with narrow slit openers is used (the fertiliser concentration is increased around the seed).

Rates may be increased by 50% when air seeders are used operating at high pressures with wide openers. Air seeders spread the fertiliser bands when operating at high pressures reducing the fertiliser concentration around the seed. [13]

5.1.3 Fungi and soil health

Arbuscular Mycorrhizal (AMF, previously known as VAM) is a fungus that penetrates the roots of a vascular plant in order to help them to capture nutrients from the soil. These fungi are scientifically well known for their ability to uptake and transport mineral nutrients from the soil directly into host plant roots. Approximately 80% of known plant species, including most economically important crops, have a known symbiosis with them.

The microscopic fungal fibres vastly extend the root system. They extract water and nutrients from a large volume of surrounding soil, and bring them to the plant, improving nutrition and growth. A plant's root system, however big, can never be as

12 Moinuddin, S., & Afridi, M. M. R. K. (1997). Grain yield and quality of triticale as affected by progressive application rates of nitrogen and phosphorus fertiliser. *Journal of plant nutrition*, *20*(4–5), 593–600.

13 DinoFert. (2016). Triticale. http://www.dinofert.com.au/technical-information/plant-nutrition-guide/item/149-triticale

extensive as the network of fungal fibres. The microscopic filaments grow through the soil and reach much more nutrients than the roots would.

In cropping systems, most plants are mycorrhizal and depend, to varying degrees, on these fungi to supply them with nutrients such as phosphorus and zinc. In turn, the plant hosts the fungus and supplies it with carbohydrates.

This mutually beneficial partnership between plants and soil fungi has existed as long as there have been plants growing in soil. Unfortunately, these beneficial mycorrhizal fungi are destroyed in the development of human-made landscapes, causing vegetation in these environments to struggle.

Unlike saprobic soil fungi, which colonise and break down organic matter and do not require a host plant in the system to complete their lifecycle, arbuscular mycorrhizal fungi (AMF), the type found in cropping systems, do require the presence of a host to reproduce and are therefore called obligate symbionts. They produce spores as a means of survival in soil during the absence of a host (e.g. a clean fallow) and then germinate and colonise host roots. The longer the fallow, the less chance of survival of these spores and this is the cause of the syndrome that is called 'Long Fallow Disorder' (LFD). Hyphae in soil or in roots in the soil may also grow to new roots however they survive for less time in the soil than the spores.

AMF levels can be severely reduced by long periods of fallow, such as those induced by drought, or the growth of non-host crops. Knowledge of the P and Zn levels in your soil and supplementation with fertiliser if required could avoid unexpected yield reduction due to nutrient deficiencies.

Primarily, LFD is a phosphorus or zinc deficiency of the plant and can be overcome by the application of P and/or Zn fertilisers. Having adequate populations of mycorrhizal fungi present in soils therefore can be beneficial and in some cases essential for crop growth. Without mycorrhizae, much higher amounts of P and/or Zn fertiliser are required to attain the same level of productivity as when plants are mycorrhizal.

When reintroduced to the soil, the mycorrhiza colonizes the root system, forming a vast network of filaments. This fungal system retains moisture while producing powerful enzymes that naturally unlock mineral nutrients in the soil for natural root absorption.

Maintaining high mycorrhizal populations promotes good crop growth and the efficient use of P and Zn fertilisers. Many crop species require only half the phosphate concentration in soil when they are colonised by AMF as they do without AMF for the same level of production. [14]

The colonisation of rye roots with vesicular-arbuscular (VA) mycorrhizal fungi was investigated at two sites, cultivated using conventional or biological-dynamic farming methods. The VAM infection rate and infected root length were significantly higher at the biologically-dynamic cultivated site. It is suggested that these differences are due to several factors, such as the use of fertilisers and agro-chemicals, and the influence of crop rotation. [15]

Management to optimize mycorrhizae

If you suspect low *AM*:

- Grow crops with low or very low mycorrhizal dependency eg wheat or barley – they won't suffer much yield loss but will still increase the AM inoculum for following crops.
- Avoid non-mycorrhizal crops, as they will not increase AMF inoculum status.
- If you wish to grow a crop of high mycorrhizal dependency for reasons such as good price, apply high rates of P and Zn fertilisers.

14 Seymour N. (2009). GRDC Update Papers: Mycorrhizae and their influence on P nutrition. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2009/09/mycorrhizae-and-their-influence-on-p-nutrition

15 Sattelmacher, B., Reinhard, S., & Pomikalko, A. (1991). Differences in Mycorrhizal Colonization of Rye (Secale cereale L.) Grown in Conventional or Organic (Biological-dynamic) Farming Systems. *Journal of Agronomy and Crop Science*, *167*(5), 350–355.

- Adopt zero or reduced tillage practices during fallow periods, as this is less harmful to AMF than frequent tillage. [16]

5.1 Crop removal rates

Each tonne of triticale harvested will remove approximately 23 kg N per ha from the paddock (Table 3). So, if targeting 3 t per ha then a minimum of 69 kg N per ha should be applied just to cover removal. If grazing is also included or soil nitrogen levels are low, additional N should be applied.

Table 3: *Nutrients removed (kg) per tonne of grain production.*

Crop type	Nitrogen	Phosphorus	Potassium	Sulfur
Wheat	21	3.0	5	1.5
Triticale	21	3.0	5	1.5
Barley	20	2.7	5	1.5
Oats	17	2.5	4	1.5

Source: Agriculture Victoria

5.2 Soil testing

Key points:

- A range of soil test values used to determine if a nutrient is deficient or adequate is termed a critical range.
- Revised critical soil test values and ranges have been established for combinations of nutrients, crops and soil.
- A single database collated more than 1892 trials from Western Australia for different crops.
- Nutrient sufficiency is indicated if the test value is above the critical range.
- Where the soil test falls below the critical range there is likely to be a crop yield response from added nutrients.
- Critical soil test ranges have been established for 0 to 10 cm and 0 to 30 cm of soil.
- Soil sampling to greater depth is considered important for more mobile nutrients (N, K and S) as well as for pH and salinity.
- Use local data and support services to help integrate critical soil test data into profitable fertiliser decisions.

Accurate soil tests allow landholders to maximise the health of their soils and make sound decisions about fertiliser management to ensure crops and pastures are as productive as possible. Up-to-date critical soil test values will help improve test interpretation to inform better fertiliser decisions. Identifying potential soil limitations enables landholders to develop an action plan (such as an appropriate fertiliser program) to reduce the potential of 'problem' paddocks. [17]

In Western Australia, profitable grain production depends on applied fertiliser, particularly nitrogen (N) phosphorus (P), potassium (K) and sulfur (S). Fertiliser is a major variable cost for grain growers. Crop nutrition is also a major determinant of profit. Both under and over-fertilisation can lead to economic losses due to unrealised potential or wasted inputs.

Before deciding how much fertiliser to apply, it is important to understand the quantities of available nutrients in the soil and where they are located in the soil

16 Seymour N. (2009). GRDC Update Papers: Mycorrhizae and their influence on P nutrition. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2009/09/mycorrhizae-and-their-influence-on-p-nutrition

17 DAFWA. (2016). Soil sampling and testing on a small property. https://www.agric.wa.gov.au/small-landholders-western-australia/soil-sampling-and-testing-small-property

profile. It is also important to consider whether the fertiliser strategy aims to build, maintain or mine the soil reserves of a particular nutrient.

Soil test critical values indicate if the crop is likely to respond to added fertiliser, but these figures do not predict optimum fertiliser rates. Soil test results can be compared against critical nutrient values and ranges, which indicate nutrients that are limiting or adequate.

When considered in combination with information about potential yield, last year's nutrient removal and soil type, soil tests can help in making fertiliser decisions.

Principal reasons for soil testing for nutrition include:

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

Soil acidity or alkalinity can influence the amount of nutrients available to plants. Table 4 demonstrates nutrient constraints based on soil pH.

Table 4: *Soil classifications for pH (1:5 soil:water).*

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

Source: DAFWA

Why Test Soil?

Soils can be tested for a range of reasons. For example, to estimate how much water can be stored, to identify the depth of root barriers or subsoil constraints (such as acidity, high aluminium, high levels of boron or salinity) and to quantify the potential occurrence of a soil-borne disease.

Principal reasons for soil testing for nutrition include:

- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity) and salinity, which affect the crop demand as well as the ability to access nutrients;
- zoning paddocks for variable application rates; and

- as a diagnostic tool, to identify reasons for poor plant performance. Soil test results are part of the information that support decisions about fertiliser rate, timing and placement.

To determine micronutrient status, plant tissue testing is usually more reliable. [18]

MORE INFORMATION

Soil Nutrient testing: How to get meaningful results.

Soil testing for crop nutrition – Western region factsheet.

Basic Requirements

There are three basic steps that must be followed if meaningful results are to be obtained from soil testing. These are:

1. To take a representative sample of soil for analysis,
2. To analyse the soil using the accepted procedures that have been calibrated against fertiliser experiments in that particular region and
3. To interpret the results using criteria derived from those calibration experiments.

Each of these steps may be under the control of a different person or entity. For example, the sample may be taken by the farmer manager or by a consultant agronomist; it is then sent to an analytical laboratory; and finally the soil test results are interpreted by an agronomist to develop recommendations for the farmer. [19]

5.2.1 Types of test

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

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

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

Other measurements that aid the interpretation of soil nutrient tests include soil pH, percentage of gravel in the soil, soil carbon/organic matter content, P sorption capacity [currently measured as Phosphorus Buffering Index (PBI)], electrical conductivity, chloride and exchangeable cations (CEC) including aluminium. [20]

Depth for nutrient sampling

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

The importance of subsoil K and S contributions to plant nutrient uptake has also been known for a long time. To obtain more comprehensive soil data, including nutrient data, sampling to 30 cm should be considered, providing there are no subsoil constraints (Photo 3). Collecting deeper soil samples does raise issues of logistics and cost, which should be discussed with soil test providers. One suggested approach is to run a comprehensive suite of soil tests on all 0 to 10 cm samples and only test for N, K, S and salinity in 10 to 30 cm samples. On sands, P can also be tested for at depth.

18 GRDC (2014). Crop nutrition: Soil testing for crop nutrition – western region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-west

19 Loch D. Soil nutrient testing: how to get meaningful results. https://www.daf.qld.gov.au/__data/assets/pdf_file/0006/65985/Soil-Nutrient-Testing.pdf

20 GRDC (2014). Crop nutrition: Soil testing for crop nutrition – western region Factsheet. www.grdc.com.au/GRDC-FS-SoilTestingW

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

Photo 3: *Nutrients, even relatively immobile ones such as phosphorus (P), can move down the profile in sandy soil, so testing nutrient reserves to depth can be useful.*

Source: GRDC, Photo: Gavin Sarre

Collecting soil samples for nutrient testing

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

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

To ensure that a sample is representative:

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

Critical values and ranges

A soil test critical value is the soil test value required to achieve 90% of crop yield potential. The critical range around the critical value indicates the reliability of the test. The narrower the range the more reliable the data (Table 5 and 6).

Table 5: *Summary table of critical values (mg/kg) and critical ranges for the 0–10 cm sampling layer:*

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

Source DAFWA in GRDC

Table 6: *Summary table of critical values (mg/kg and kg/ha) and critical ranges for the 0–30 cm sampling layer.*

Nutrient	Crop	Critical values (mg/kg)	Critical range (mg/kg)
P	Wheat	11	10–11
	Lupins	9	8–10
	Canola	N/A	N/A
K	Wheat	N/A	N/A
	Lupins	N/A	N/A
	Canola	31	28–34
S	Wheat	4.6	4.0–5.3
	Lupins	N/A	N/A
	Canola	7.1	6.7–7.5

Source DAFWA and Murdoch University in GRDC.

The critical value indicates if a nutrient is likely to limit crop yield based on whether the value is greater than or less than the upper or lower critical range value (Figure 1). If the soil test value is less than the lower limit, the site is likely to respond to an application of the nutrient. For values within the range there is less certainty about whether a response will occur. In this case, growers have to exercise judgement about the costs and benefits of adding fertiliser in the forthcoming season, versus those associated with not applying. If the soil test is above the critical range, fertiliser is applied only to maintain soil levels or to lower the risk of encountering deficiency. The larger the range around the critical value, the lower the accuracy of the critical value. [21]

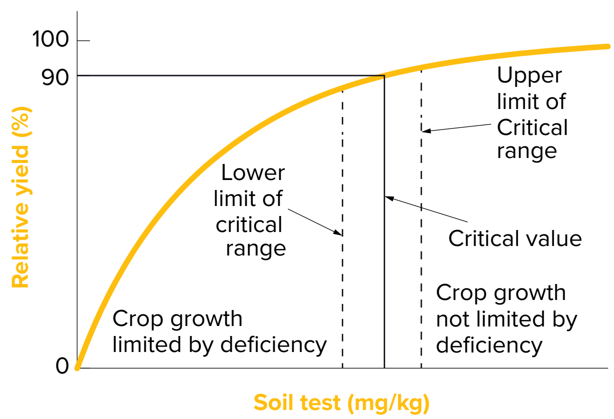

Figure 1: *Generalised soil test response calculation curve. A generalised soil test–crop response relationship defining the relationship between soil test value and per cent grain yield expected. A critical value and critical range are defined from this relationship. The relative yield is the unfertilised yield divided by maximum yield, expressed as a percentage. The BFDC Interrogator fits these curves and estimates critical value and critical range. Normally 90 per cent of maximum yield is used to define the critical value but critical values and ranges at 80 per cent and 95 per cent of maximum yield can also be produced.*

Source: DAFWA, Murdoch University in GRDC

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

5.2.2 West Australian Soil Quality Program

Key Points

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

www.soilquality.org.au provides an, interactive resource to the Australian grains industry on soil quality, including soil biology as well as soil chemistry and physics. The web site allows growers to benchmark their paddocks against values for their local catchment and region as well as against expert opinion. This information aids growers to determine if they are heading in the right direction with their systems and practices and supports growers to improve soil management practices. The Soil Quality Monitoring Program and the web site www.soilquality.org.au are expanding to include grainproducing areas across Australia. This will give growers across Australia access to regionally specific data on soil biological, chemical and physical constraints to production. This will aid the Australian grains industry to make better management decisions. [22]

5.3 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.

Why measure nutrients in plant tissues?

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

What plant tissue analysis shows

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

DO'S

- Sample the correct plant part at the specified time or growth stage.
- Use clean plastic disposable gloves to sample to avoid contamination.

22 Soilquality.org. Western Australian Soil quality program. http://www.soilquality.org.au/factsheets/w-a-soil-quality-program

- 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 despatched to the laboratory immediately, to arrive before the weekend.
- Generally sample in the morning while plants are actively transpiring.

DON'TS

- Avoid spoiled, damaged, dead or dying plant tissue.
- Don't sample plants stressed by environmental conditions.
- Don't sample plants affected by disease, insects or other organisms.
- Don't sample soon after applying fertiliser to the soil or foliage.
- Avoid sample contamination from dust, fertilisers, 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[23]

Table 7: *Plant tissue requirements for nutrient testing.*

Crop	Growth Stage to sample	Plant Part	Number required
Triticale	Seedling to early tillering (GS 14 -21)	Whole tops cut off 1 cm above ground	40
	Early tillering to 1st 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 1st node (GS21-31)	Youngest expanded blade (YEB) plus next 2 lower blades.	40

Source: BackPaddock

5.4 Nitrogen

Key points:

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

23 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

- Soil testing and nitrogen models will help determine seasonal nitrogen requirements.
- Some farmers believe that triticale produces more grain under the same amount of applied nitrogen in wheat and barley. [24]

The two forms of soil mineral N absorbed by most plants are nitrate (NO3N) and ammonium (NHþ4N) (Figure 2). In well-aerated soils during the growing season NO3N becomes the main form of N available for crops as microbial activity quickly transforms NHþ4N into NO3N. It is crucial to keep the NO3N levels at an adequate level because, on one hand, too low levels of soil NO3N can limit crop production and, on the other hand, too high amounts of NO3N can lead to environmental pollution. The levels of soil NO3N vary across space and over time. Proper agricultural management needs to consider both site-specific variations as well as temporal patterns in soil NO3N to supply optimum amounts from both organic and mineral sources. [25]

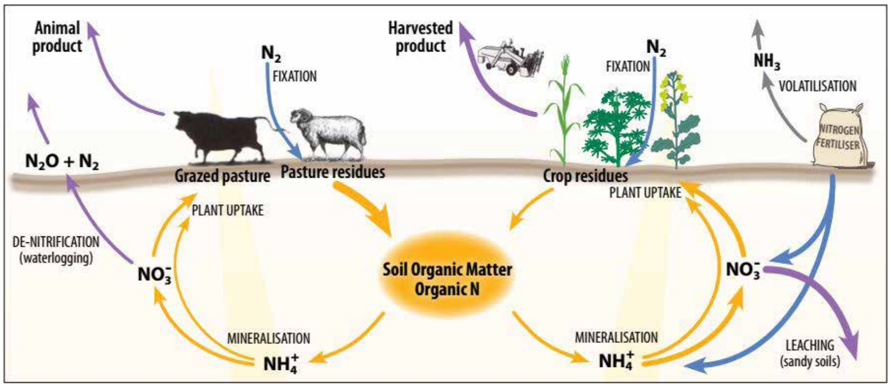

Figure 2: *Principle nitrogen cycling pathways in a mixed cropping/pasture system (adapted from Peverill et al. 1995).*

Source: Soilquality.org

Give particular attention to nitrogen supply. Triticale used for grazing and grain could use up to 100 kg/ha of N. Consider applying 60–100 kg/ha of N as a topdressing if soil nitrogen levels are low. Long fallow paddocks following good legume pastures generally have satisfactory nitrogen levels. Long fallow paddocks have the highest yield potential because of stored moisture and have the greatest potential to respond to soil nitrogen. Yield increases are likely when nitrogen is applied to paddocks with low nitrogen status. The contribution of pulse crops and pastures to soil nitrogen depends on the amount of plant material produced and/or the subsequent grain yield. The actual amount of soil nitrogen accumulated is highly variable. [26]

Triticale has been found to response well to nitrogen application under drought conditions (Figure 3). [27]

24 Ground Cover Issue 59 – Triticale. 1/01/2006. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-59/Triticale

25 Ladoni, M., Kravchenko, A. N., & Robertson, G. P. (2015). Topography Mediates the Influence of Cover Crops on Soil Nitrate Levels in Row Crop Agricultural Systems. *PloS one*, *10*(11), e0143358.

26 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

27 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

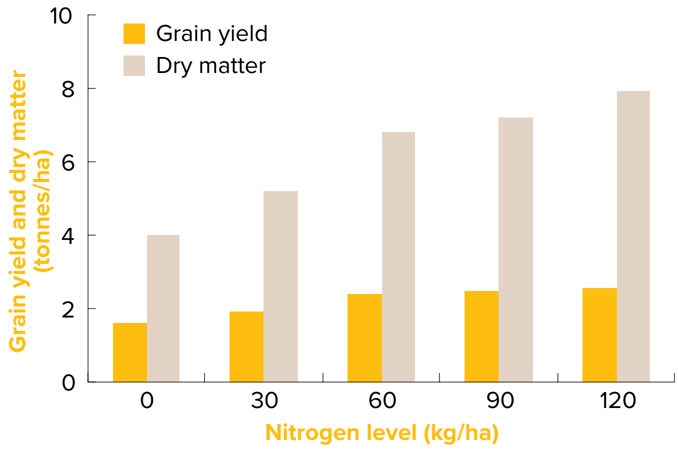

Figure 3: *Triticale grain yield and straw dry-matter response to nitrogen levels under drought conditions in Morocco.* [28]

Trials in Europe found that a N 90–120 rate to be economically and ecologically optimal for spring triticale. It resulted in the highest (4.81–4.92 Mg/ha^{-1}) grain yield. [29]

Additional nitrogen is likely to be required for maximum grain yield, particularly if the crop has been grazed.

IN FOCUS

Responses of triticale, wheat, rye and barley to nitrogen fertiliser

A hexaploid triticale from Mexico and local cultivars of wheat, rye and barley, each at five levels of fertiliser nitrogen (0, 35, 70, 105 and 140 kg N/ha) with four replications, were grown in a field experiment in South Australia. A visually discernible response to nitrogen fertiliser by all four genotypes from an early stage was confirmed by quantitative sampling at tiliering, anthesis and maturity. Responses in plant dry weight to 105 kg N/ha were maintained until anthesis but grain yield responses were significant only at 35 kg N/ha. Total dry matter production responses at maturity to more than 35 kg N/ha were small. Numbers of tillers and heads were increased by nitrogen additions up to 140 and 105 kg N/ha, respectively, and plant height measurements showed general increases to 70 kg N/ha with significant lodging at higher nitrogen levels in both rye and triticale. For all genotypes, thousand grain weight decreased with increasing level of nitrogen supply while grain and straw nitrogen increased up to levels of 140 and 105 kg N/ha, respectively. Nitrogen supply had little effect on maturity, plants at 0 and 140 kg N/ha reaching anthesis less than a day apart. The lack of a significant nitrogen x genotype interaction in nearly all the data suggests that the triticale does not differ in its nitrogen nutrition from the traditional cereals. Triticale consistently outyielded the other cereals in total dry matter production followed by the rye, wheat and barley in that order. Grain yield was highest in the wheat and least in the rye, the latter also being the least responsive to nitrogen.

28 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

29 Janušauskaitė, D. (2013). Spring triticale yield formation and nitrogen use efficiency as affected by nitrogen rate and its splitting. *Zemdirbyste-Agriculture*, *100*(4), 383–392.

The advantage of the triticale lay in its high grain protein and lysine content combined with good yield. [30]

Pre-plant N increased forage production and frequently produced more boot stage triticale biomass. It also tended to increase P uptake, but reduced P and forage protein concentrations likely due to plant dilution. [31]

Trials outside Canberra exploring crop management of dual purpose cereals suggest that Nitrogen should be applied at sowing to ensure good early plant growth and the build-up of a feedbank. Post-sowing nitrogen application should be left until after grazing and should not be applied just before grazing due to the risk of high forage nitrate levels. High nitrate in forage can lead to nitrite toxicity in grazing livestock, especially under cool, cloudy conditions. Growers may safely apply 50 kilograms of nitrogen per hectare as urea immediately after grazing finishes to boost plant recovery. [32]

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. However, in most of the newer varieties lodging is not considered a problem. The likelihood of lodging is increased by high rates of nitrogen fertiliser and under irrigated conditions. [33]

5.4.1 Nitrogen deficiency symptoms in cereals

What to look for

Paddock

- Light green to yellow plants particularly on sandy soils or unburnt header or swathe rows (Photo 4).
- Double sown areas have less symptoms if nitrogen fertiliser was applied at seeding.

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 (Photo 5).
- Other leaves start to yellow and oldest leaves change from yellow to almost white.
- 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.

30 Graham, R. D., Geytenbeek, P. E., & Radcliffe, B. C. (1983). Responses of triticale, wheat, rye and barley to nitrogen fertiliser. *Animal Production Science*, *23*(120), 73–79.

31 Brown, B. (2011). Nitrogen Timing for Boot Stage Triticale Forage Yield and Phosphorus Uptake. *Forage and Grazinglands*, *9*(1), 0–0.

32 Lush D. (2014). Ground Cover Issue 109: Mar-Apr 2014. Rules of thumb for grazing cereals. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-109-Mar-Apr-2014/Rules-of-thumb-for-grazing-cereals

33 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Photo 4: *Nitrogen deficiency on unburnt header row.*

Source: DAFWA

Photo 5: *Deficient plants are smaller with yellow leaves and fewer tillers.*

Source: DAFWA

What else could it be?

Condition	Similarities	Differences
Diagnosing waterlogging in cereals	Pale plants with oldest leaves most affected	Root browning or lack of feeder roots and wet soil
Diagnosing potassium deficiency in wheat	Pale plants with oldest leaves most affected	Differences include more marked leaf tip death and contrast between yellow and green sections of potassium deficient plants. Tillering is less affected.
Diagnosing molybdenum deficiency in cereals	Pale poorly tillered plants	Molybdenum deficiency affects the middle leaves first and cause white heads, shrivelled grain and delayed maturity

Deficiency symptoms can be treated with Nitrogen fertiliser or foliar spray. NOTE: There is a risk of volatilisation loss from urea or (ammonium sources of nitrogen on alkaline soils) when topdressesd on dry soils in dewy conditions. Losses rarely exceed 3% per day. [34]

VIDEOS

WATCH: GCTV14: Nitrogen deficiency.

34 DAFWA. Diagnosing Nitrogen deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-wheat

5.4.2 Managing nitrogen

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 chances 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. [35]

Nitrogen fertilisers are a significant expense for broadacre farmers so optimising use of fertiliser inputs can reduce this cost. There are four main sources of nitrogen available to crops: stable organic nitrogen, rotational nitrogen, ammonium and nitrate. To optimise plants' ability to use soil nitrogen, growers should first be aware of how much of each source there is. The best method of measuring these nitrogen sources is soil testing.

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 nitrogen during crop emergence and establishment is critical. Nitrogen use efficiency can be improved by delaying fertiliser application until the crop's roots system is adequately developed. This can be 3–4 weeks after germination.

Later nitrogen 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 nitrogen will be achieved. An advantage of late applications (1st node visible) is that growers have a better idea of yield potential before applying the nitrogen. [36]

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 8 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 134 kg N/ha.

Clearly predicting yield during the growing season is crucial to allow growers to make tactical decisions on N management. Recent experience 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. [37]

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

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

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

Table 8: *Nitrogen 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
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

5.5 Phosphorus

Key Points

- Phosphorus (P) is one of the most critical and limiting nutrients in agriculture in Australia.
- Phosphorous cycling in soils is complex.
- Only 5–30% of phosphorus applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus fertiliser is best applied at seeding.
- Compared with bread wheats, triticale and rye have been found to be more efficient in using P at low levels of P supply.
- Triticale has been classified as phosphorus efficient (higher yielding under than other cultivars under low phosphorus supply) and/or phosphorus responsive (higher yielding than other cultivars under high phosphorus supply). [38]

After nitrogen stress, phosphorus is the second most widely occurring nutrient deficiency in cereal systems around the world. [39] Phosphorus is essential for plant growth, but few Australian soils have enough phosphorus for sustained crop and pasture production. Many soils have large reserves of total phosphorus, but low levels of available phosphorus. Complex soil processes influence the availability of phosphorus applied to the soil, with many soils able to adsorb or 'fix' phosphorus, making it less available to plants (Figure 4). A soil's ability to fix phosphorus must be measured when determining requirements for crops and pastures. [40]

38 Ortiz-Monasterio, J. I., Pena, R. J., Pfeiffer, W. H., & Hede, A. H. (2002, June). Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In *Proc. of the 5th Int. Triticale Symp., Annex* (Vol. 30).

39 Ortiz-Monasterio, J. I., Pena, R. J., Pfeiffer, W. H., & Hede, A. H. (2002, June). Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In *Proc. of the 5th Int. Triticale Symp., Annex* (Vol. 30).

40 Soilquality.org. Phosphorus NSW. http://www.soilquality.org.au/factsheets/phosphorus-nsw

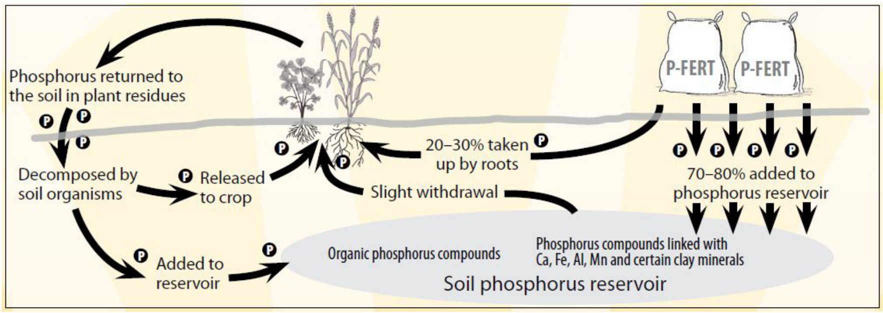

Figure 4: *The phosphorus cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited (from Fertiliser Industry Federation of Australia Inc., 2000).*

Source: Soilquality.org

There has been substantial improvement (e.g., genetic gains) in terms of P responsiveness in triticale, however there has been little improvement in terms of phosphorus use efficiency; i.e. performance under low phosphorus conditions. Research in Mexico found that triticale was responsive to P applications with grain yields in some genotypes almost three times higher in the 80 kg P2O5 application treatment. [41]

Phosphorus application has also been found to influence triticale growth stages. One study found that plots treated with phosphorus (90 kg ha^{-1}) produced more days to anthesis (126), plant height (114 cm) and leaf area cm^2 (21) while more days to physiological maturity (167) was formed by 60 kg P ha^{-1}. [42]

Triticale responds well to phosphorus application under drought conditions (Figure 5). [43]

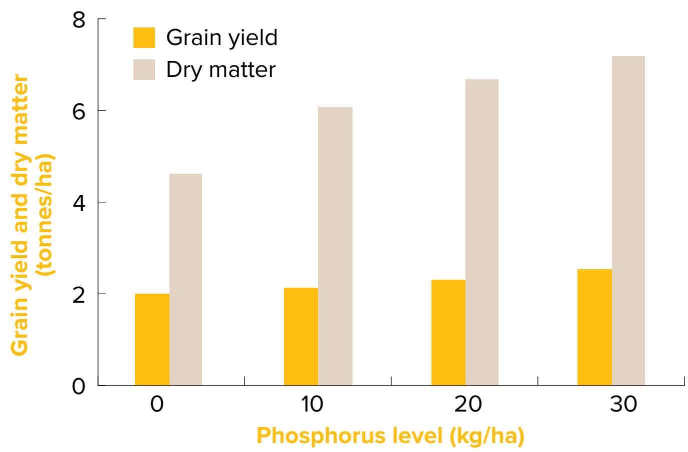

Figure 5: *Triticale grain yield and straw dry-matter response to phosphorus levels under drought conditions in Morocco.* [44]

41 Ortiz-Monasterio, J. I., Pena, R. J., Pfeiffer, W. H., & Hede, A. H. (2002, June). Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In *Proc. of the 5th Int. Triticale Symp., Annex* (Vol. 30).

42 Iqbal, B., Ahmad, B., Ullah, I., Khan, A. A., Anwar, S., Ali, A., ... & Khan, S. (2016). Effect of phosphorus, sulfur and different irrigation levels on phenological traits of Triticale. *Pure and Applied Biology*, *5*(2), 303.

43 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

44 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

Another study found that, under field conditions, triticale presented higher grain yield response to P than seven wheat cultivars. [45]

A study in south-western Australia found that on an acidic soil, triticale required from 50 to 70% less P than wheat, but on less acidic soil it required 100% more P. [46]

Phosphorus deficiency is thought to be responsible for biomass reduction of triticale in nutrient solution with aluminium. One study suggests that in previous experiments, phosphorus deficiency is probably the most important limiting factor in acid nutrient solutions with Aluminium. [47]

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

5.5.1 Phosphorus in WA

Most soils across the WA wheatbelt now exceed critical levels for soil phosphorus. Modelling work suggests many growers can start to reduce phosphorus inputs without any impact on yields. Some growers are now lowering their phosphorus applications by 20 to 30%. However, any adjustments to phosphorus rates need to be done in relation to soil pH and other production constraints because phosphorus requirements will be higher on acid and non-wetting soils and in areas prone to root disease. The addition of lime to increase soil pH has been found to improve crop response to nutrients such as phosphorus. While most cropping paddocks in the western region have sufficient phosphorus levels, more than three-quarters have surface pH levels that affect grain yield potential. A large number have a subsoil pH below the critical level of 4.8. Once surface soil pH drops below 5.5, phosphorus availability is compromised – even in soils with more than the critical level of phosphorus. The problem is that fixing acid soils is relatively expensive – especially for growers in the eastern WA wheatbelt who operate under very tight profit margins. One recommendation is for growers to divert money they might have spent on phosphorus applications into targeted liming of acid soils to boost yield potential. [48]

5.5.2 Managing phosphorus

Key points:

- After decades of consistent phosphorus (P) application, 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.

45 Ben, J. R. (1991). Response of triticale, wheat, rapeseed and lupine to phosphorus in soil. In *2. Proceedings of the International Triticale Symposium. Passo Fundo (Brazil). 1–5 Oct 1990.*.

46 Bolland, M. D. A. (1992). The phosphorus requirement of different crop species compared with wheat on lateritic soils. *Fertilizer research*, *32*(1), 27–36.

47 Quartin, V. L., Azinheira, H. G., & Nunes, M. A. (2001). Phosphorus deficiency is responsible for biomass reduction of triticale in nutrient solution with aluminum. *Journal of plant nutrition*, *24*(12), 1901–1911.

48 Paterson J. (2014). Dr Craig Scanlon on Soil Acidity and phosphorus in western region. Ground Cover Supplement, Issue 108, January – February 2014.

- Work with an adviser to refine your fertiliser strategy.
- Phosphorus (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 to 30 centimetres) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Applying P at depth (15 to 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 nitrogen (N), to this adjusted yield potential. [49]

MORE INFORMATION

Crop nutrition Phosphorus management Factsheet – Western region.

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. [50]

Phosphorus fertiliser and, where necessary, nitrogen fertiliser are recommended in the same amounts as recommended for wheat.

Mycorrhiza fungi play an important role in plant uptake of phosphorus (P).The P uptake by wheat, rye, and triticale was 10, 64, and 35%, respectively, higher with rather than without mycorrhizal infection. Triticale followed wheat, with similar mycorrhizal dependency. [51]

Symptoms

Paddock

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows.
- Plants look unusually water-stressed despite adequate environmental conditions (Photo 6).
- Affected areas are more susceptible to leaf diseases.

Plant

- In early development, usually in cases of induced phosphorus deficiency, seedlings appear to be pale olive green and wilted (Photos 7 and 8).
- 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 nitrogen deficiency, necrosis (death) of these chlorotic (pale) areas is fairly rapid, with the tip becoming orange to dark brown and shrivelling, while the remainder turns yellow. At this stage the second leaf has taken on the early symptoms of phosphorus deficiency.
- By tillering, (uncommon) symptoms of severe deficiency are dull dark green leaves with slight mottling of the oldest leaf.

49 GRDC (2012). Crop nutrition: Phosphorus management – Western region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2012/11/grdc-fs-phosphorusmanagements

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

51 Pandey, R., Singh, B., & Nair, T. V. R. (2005). Impact of arbuscular-mycorrhizal fungi on phosphorus efficiency of wheat, rye, and triticale. *Journal of plant nutrition*, *28*(10), 1867–1876.

Photo 6: *Stunted early growth with reduced tillers in P deficient crop on the left.*

Source: DAFWA

Photo 7: *P deficient plants on the left are later maturing with fewer smaller heads.*

Source: DAFWA

Photo 8: *Dark leaves with necrosis moving down from the tip of the oldest leaf.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing nitrogen deficiency in wheat	Small less tillered and light green plants	Phosphorus deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing.
Diagnosing molybdenum deficiency in cereals	Small less tillered and light green plants	Phosphorus deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing.
Diagnosing potassium deficiency in wheat	Small less tillered and light green plants	Phosphorus deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing.

Plants have a high requirement for phosphorus during early growth. As phosphorus is relatively immobile in the soil, topdressed or sprayed fertiliser cannot supply enough to correct a deficiency.

Phosphorus does leach on very low PBI (a measure of phosphorus retention) sands, particularly on coastal plains. Topdressing is effective on these soils. [52]

52 DAFWA. Diagnosing Phosphorus deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-wheat

MORE INFORMATION

Crop nutrition: Phosphorus management – Western region Factsheet

VIDEOS

WATCH: GCTV13: Phosphorus deficiency.

WATCH: Improving phosphate use efficiency.

Soil testing

Testing of the phosphorus levels in your soil is important and will help in the budgeting of your phosphorus dollar. Thirty to 50% of WA growers conduct regular soil testing, the highest rate in the country.

Taking random samples of the surface soil (0 to 10 cm), typically from between the rows, from different yield zones of cropping paddocks is one way to understand the P status of the soil and, consequently, to inform decisions about fertiliser expenditure and application rates. Using GPS to sample the same site every three to four years is another approach.

This allows the grower to track changes in soil test P, potassium (K) and pH over time. Soil test results will indicate if there is likely to be a response to a fertiliser nutrient. This is the start of the process for estimating the approximate amount of nutrient required to achieve a target yield. [53]

The release of phosphorus is related to:

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

Available phosphorus tests like the Colwell and Olsen's phosphorus test don't measure available phosphorus. Rather they express an indication of the rate at which phosphorus may be extracted from the soils. This indicator of rate is calibrated with field trials. There is a relationship between Total Soil Phosphorus and Colwell Phosphorus and this can enable you to predict when a given level of phosphorus input (fertiliser) or output (product removal) will result in a risk of phosphorus rate of supply becoming a limiting factor. [54]

5.6 Sulfur

Sulfur is an essential plant nutrient required for the production of amino acids which in turn make up proteins. In cereals lower sulfur levels lead to lower protein and given this affects the quality of the flour, the price received for this grain will be reduced. Lack of sulfur will also affect the oil content and hence the price received for canola. Yield losses also occur in low sulfur situations. Ideally, plants will take up sulfur at the same levels as phosphorus.

Sulfur is present in varying amounts in nearly all soils. Soils with clay and gravel have generally more sulfur present than sandier soils from high rainfall areas. The sandier soils from higher rainfall areas do not have any ability to restrict the leaching of water soluble sulfur. Sulfur remaining in plant residues is readily recycled into the soil. [55]

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. [56]

The forage production potential of triticale and wheat is essential to many livestock producers. Very few data are available concerning the effects of sulfur fertilisation on production and quality of triticale or wheat forage. Greenhouse research was conducted to evaluate the addition of S as either ammonium thiosulfate (ATS) or ammonium sulfate (AS) on production and quality of triticale and wheat forage on four different soils. Sulfur fertilisation increased forage yields and S concentrations of

53 GRDC (2012). Crop nutrition: Phosphorus management – Western region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2012/11/grdc-fs-phosphorusmanagements

54 Bailey G, Brooksby T. Phosphorus in the South East Soils.

55 Summit Fertilisers. Sulfur. http://www.summitfertz.com.au/research-and-agronomy/sulphur.html

56 GRDC (2014). Crop nutrition: Soil testing for crop nutrition – southern region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

both crops on all soils, and in many cases, resulted in higher N concentrations in the forage. Sulfur fertilisation also increased *in vitro* digestibility of wheat, but had little effect on triticale digestibility. Both S sources performed similarly. Application of S after the first clipping was effective in increasing second clipping forage production on three of the four soils, and forage S concentrations were dramatically increased for both crops on all soils. Although the magnitude of response varied, S fertilisation was effective in increasing production and quality of triticale and wheat forage grown in the greenhouse. [57]

Treatments of nitrogen and phosphorous fertilisers have been found to significantly increase the dry matter, sulfur concentrations and sulfur uptake of triticale compared to unfertilised treatments. [58]

One study found that Sulfur (20 kg ha^{-1}) applied to plots of triticale produced higher days to anthesis (126). [59]

Sulfur in WA

Historically, S has been adequate for crop growth because S is supplied in superphosphate, in rainfall in coastal areas and some from gypsum. In the Southern region sulfur-responsive soils are uncommon in cereals, but can be seen in canola. Sulfur inputs to cropping systems have declined with the use of TSP, MAP and DAP which are low in S. Sulfur is also subject to leaching and in wet seasons may move beyond the root zone.

Sandy-textured soils in Western Australia are naturally low in sulfur and applied sulfur is readily leached from the top 10 cm, especially in high rainfall areas.

The use of fertilisers containing sulfur somewhat masks the low levels of sulfur present in the soil, however the introduction of more sensitive crops such as canola and the change to compound fertilisers that are low in sulfur has increased the frequency of sulfur deficiency seen in crops. High rainfall can leach sulphate from the root zone early in the growing season, leaving young crops deficient. Other factors that can induce deficiency in crops include sub-soil constraints such as acidity, sodicity and hardpan, and the level nitrogen in the soil can limit the crop's ability to access subsoil sulphate.

The mobile nature of sulfur in the soil, and its capacity to be mineralised through the breakdown of organic matter, makes it difficult to reliably predict when a crop will respond to an application of sulfur.

A synergistic relationship exists between sulfur, nitrogen and phosphorus that affects plant uptake and efficient use of these nutrients. Too much nitrogen can induce sulfur deficiency in plants. Grain yields increase when all three nutrients are in sufficient supply and in the correct ratio.

Most sulfur present in the soil is bound in organic compounds but plants can only take up the mineral sulphate form. Cultivation releases sulfur held in organic matter. In no-till systems soil organic matter breaks down slowly, releasing mineral sulfur for crop use. Sulfur mineralisation is low in cooler months, as is root exploration, which can cause temporary deficiency in crops, seen as patches that disappear when the soil temperature increases. Mineralisation is higher in the warmer months and under moist soil conditions. Sulphate adsorption occurs in the soil layers below 10 cm, which can make a significant contribution to crop growth once crop roots have reached the subsoil.

The rate of sulphate leaching is highly variable, depending on seasonal conditions and the water holding capacity of the soil, and is closely related to the rate of nitrate leaching. These two nutrients are best considered together when planning fertiliser

57 Feyh, R. L., Lamond, R. E., Whitney, D. A., & Sears, R. G. (1993). Sulfur fertilisation of wheat and triticale for forage production 1. *Communications in Soil Science & Plant Analysis*, *24*(5–6), 443–455.

58 Lasztity, B. (1993). The variation of sulfur contents and uptakes in triticale during growth [in Hungary]. *Agrochimica (Italy).*

59 Iqbal, B., Ahmad, B., Ullah, I., Khan, A. A., Anwar, S., Ali, A., ... & Khan, S. (2016). Effect of phosphorus, sulfur and different irrigation levels on phenological traits of Triticale. *Pure and Applied Biology*, *5*(2), 303.

applications at seeding and post-seeding to compensate for the movement of these nutrients down the profile under the current seasonal conditions. [60]

Sulfur application recommendations

In most situations (depending on climate and soil type) the recommended value, above which wheat crops will not respond to applied sulfur fertiliser, are as follows:

- 6.0 using 0–10 cm and 5.3mg S/kg using 0–30 cm across all rainfall zones
- 3.5 using 0–10 cm and 3.2mg S/kg using 0–30 cm in low rainfall zones. [61]

Deficiency symptoms

Paddock

- Areas of pale plants (Photo 9).

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 10).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red.

Photo 9: *Areas of pale plants characterise Sulfur deficiency (NOTE: many nutrient deficiencies also exhibit pale patches).*

Source: DAFWA

60 GRDC. (2015). Hot Topics: Sulfur strategies for Western region. https://grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region

61 GRDC. (2015). Hot Topics: Sulfur strategies for Western region. https://grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region

Photo 10: *Leaves remain healthy despite the yellowing.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing iron deficiency in cereals	Pale new growth.	Iron deficient plants have interveinal chlorosis.
Diagnosing group B herbicide damage in cereals	Seedlings with pale new leaves	Plants generally recover from Group B herbicide damage and leaves often have interveinal chlorosis.
Waterlogging, nitrogen, molybdenum and manganese deficiency	Pale growth.	The youngest leaves of sulfur deficient plants are affected first while the middle or older leaves are affected first with waterlogging, manganese, nitrogen and molybdenum deficiency.

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

Foliar sprays generally cannot supply enough sulfur for plant needs. [62]

Modern high analysis fertilisers will usually contain enough sulfur to supply sufficient levels to cereal crops. Canola, however, will require more than can be safely or conveniently applied using a seeding fertiliser and so extra sulfur must be applied, either before seeding as gypsum, or post seeding as Amsul, (sulphate of ammonia).

If a deficiency manifests in an established crop, this can be easily corrected with an application of sulphate of ammonia.

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

Supplies of Sulfur (Elemental or Sulphate)

Plants take up sulfur in the sulphate (SO4) form. The sulphate form is water soluble and readily leachable. The elemental form of sulfur needs to be broken down into the sulphate form before becoming available to the plant. This is achieved by a bacteria which digests the sulfur and excretes sulphate. All soils contain this bacteria. It takes about a fortnight for elemental sulfur to start breaking down, so it should be used before plant deficiency can be seen. In waterlogged conditions, where sulphate sulfur will be lost by leaching or runoff, the bacteria will become dormant, so sulfur will not be lost.

Pros and Cons of the two sulfur sources.

Sulphate Sulfur:

- Immediately available to the plant
- Water soluble
- Quick acting
- Leachable
- Can be lost with one heavy rainfall event

Elemental Sulfur:

- Sustained Release
- Not lost by leaching
- More available when maximum plant growth occurs in spring
- Will build up a sulfur "bank"
- Slow to break down.
- Not suitable to correct a visual deficiency in plants. [63]

5.7 Potassium

Key points:

- Triticale can be sensitive to potassium deficiency and responses to its application.
- Soil testing combined with plant tissue testing is the most effective means of determining potassium requirements.
- Banding away from the seed, at or within 4 weeks of sowing, is the most effective way to apply potassium when the requirement is less than 15 kg/ha.

Potassium (K) is an essential plant nutrient. Potassium has many functions including the regulation of the opening and closing of stomata, the breathing holes on plant leaves that control moisture loss from the plant. Adequate potassium increases vigour and disease resistance of plants, helps to form and move starches, sugars and oils. Available potassium exists as an exchangeable cation associated with clay particles and humus. [64]

A study in Europe found that triticale is more sensitive to potassium deficiency than phosphorus deficiency. [65]

Previous research has found that the highest rate of grain yield for triticale (6.1 t/ha–1) was obtained by application of 160 and 90 kg/ha^{-1} nitrogen and potassium, respectively. Application of different levels of Nitrogen affected grain protein of triticale, however using different amounts of potassium did not affect grain protein. [66]

63 Summit Fertilisers. Sulfur. http://www.summitfertz.com.au/research-and-agronomy/sulphur.html

64 Soilquality.org. Potassium – NSW http://www.soilquality.org.au/factsheets/potassium-nsw

65 GAJ, R. (2012). The effect of different phosphorus and potassium fertilisation on plant nutrition in critical stage and yield of winter triticale. *Journal of Central European Agriculture*, *13*(4).

66 Tababtabaei, S. A., & Ranjbar, G. H. (2012). Effect of different levels of nitrogen and potassium on grain yield and protein of triticale. *International Research Journal of Applied and Basic Sciences*, *3*(2), 390–393.

MORE INFORMATION

Mineral supplements needed when grazing cereals

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. [67]

High potassium (K): sodium (Na) ratios in wheat and some triticale varieties can induce magnesium (Mg) deficiency (tetany) in grazing stock. Surveys in southern Australia showed that all varieties of cereals tested had a K:Na ratio that could cause magnesium deficiency in livestock.

One contributing factor to the variation in animal gains is the mineral nutrition provided by cereals to grazing livestock. The magnesium (Mg) content of cereal is typically satisfactory for stock, but the high potassium (K) content and very low sodium (Na) content of forage result in a high rumen K:Na ratio, which impedes magnesium absorption in the rumen.

Livestock (sheep and cattle) grazing cereals can therefore have a sodium deficiency and a magnesium deficiency (tetany). [68]

What to look for

Paddock

- Smaller lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows (Photo 11).
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease.

Plant

- Plants appear paler and weak (Photo 12).
- 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.
- Yellowing leaf tip and leaf margins sometimes generates a characteristic green 'arrow' shape towards leaf tip.

67 GRDC (2014). Crop nutrition: Soil testing for crop nutrition – southern region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

68 Bell L, Dove H. (2012). Ground Cover Issue 98: May-June 2012. Mineral supplements needed when grazing cereals. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-98-May-June-2012/Mineral-supplements-needed-when-grazing-cereals

Photo 11: *Header rows have less symptoms.*

Source: DAFWA

Photo 12: *Potassium deficient plants may display floppy older leaves and furled flag leaf from water stress. Affected plants are paler, weak and more susceptible to leaf disease. Discoloured leaf tissue can be bright yellow.*

Source: DAFWA

What else could it be?

Condition	Similarities	Differences
Diagnosing molybdenum deficiency in cereals	Pale plants with leaf tip death.	Potassium deficient plants do not have white or rat-tail heads, and have more marked contrast between yellow and green sections of affected leaves.
Diagnosing nitrogen deficiency in wheat	Pale plants with oldest leaves most affected.	Potassium deficient plants have more marked leaf tip death and contrast between yellow and green sections of affected leaves, and tillering is less affected.
Diagnosing spring drought in wheat and barley	Water stressed plants with older leaves dying back from the tip, yellowing progressing down from tip and edges and often leaf death occurs.	The main difference is that potassium deficiency is more marked in high growth plants in good seasons.
Diagnosing root lesion nematode in cereals	Smaller, water stressed pale plants.	Root lesion nematode affected plants have 'spaghetti' roots with few feeder roots.

Top-dressing potassium will generally correct the deficiency. Foliar sprays generally cannot supply enough potassium to overcome a severe deficiency and can also scorch crops. [69]

Assessing potassium requirements

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

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

Potassium available in the soil is measured by the Colwell K or Exchangeable K soil tests. The amount of potassium needed for plant nutrition depends on soil texture (Table 9).

Table 9: *Critical (Colwell) soil test thresholds for potassium (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 potassium to be present, but are more likely to show deficiencies. Clay soils require more potassium to be present, but are more capable of supplying replacement potassium through the weathering of clay minerals.

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

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

Fertiliser types

Sulphate of potash (SOP—potassium sulphate) is usually recommended if potassium is deficient. Applying the cheaper muriate of potash (MOP—potassium chloride) also corrects potassium 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 nitrogen and potassium in a highly water soluble (and available) form, but is rarely used in broadacre farming because of its cost.

Fertiliser placement and timing

Potassium generally stays very close to where it is placed in the soil. Banded potassium has been shown to be twice as accessible to the crop as top-dressed potassium. 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 potassium drill row or seedlings may miss the higher levels of potassium. High band rates (>15 kg/ha) of potassium can inhibit sensitive crops (e.g. lupins, canola). If a paddock is severely deficient then potassium needs to be applied early in the season, at seeding or up to four weeks after. [70]

5.8 Micronutrients

Key points:

- 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.
- 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. Most soils in Western Australia (WA) are naturally deficient in the trace elements copper (Cu), zinc (Zn), manganese (Mn) and molybdenum (Mo).

Zn deficiency can severely limit annual pasture legume production and reduce cereal grain yields by up to 30%. Cu deficiency is also important because it is capable of causing total crop failure.

If 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 south-western 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.

70 Soilquality.org. Potassium. http://www.soilquality.org.au/factsheets/potassium-nsw

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. [71]

Triticale grows productively on alkaline soils where certain trace elements are deficient for other cereals. [72]

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.

In early trials it was reported that triticale commonly expressed the copper (Cu) efficiency trait derived from its cereal rye parent, and had efficiency traits for Zinc (Zn) and Manganese (Mn). Triticale usually performs remarkably well on highly calcareous soils which are often deficient in Mn and Zn and sometimes Cu. [73]

One study from Europe suggests that calcium, magnesium and potassium are the most limiting mineral nutrients to triticale yield. [74]

DAFWA recommends that managers complement soil testing (for macronutrients) with tissue testing as part of a regular fertiliser management program, to monitor the impact of fertiliser and liming programs. This will help identify approaching trace element deficiencies before production losses occur.

By using test results, managers can identify which trace elements are needed, and avoid adding expensive trace element fertilisers when they are unnecessary.

Adding high levels of nitrogen fertilisers also increases acidification, and this then needs lime to bring the pH back into the desired range. Over-use of Lime can change the pH enough that Cu, Mn and Zn become less available to plants. [75]

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.]

5.8.1 Manganese

Many triticale cultivars carry tolerance to soils high in manganese, which is typical in some soils of Australia. [76]

Deficiency symptoms

Paddock

- Manganese deficiency often appears as patches of pale, floppy plants in an otherwise green healthy crop (Photo 13).

Plant

- Frequently plants are stunted and occur in distinct patches.
- Initially, middle leaves are affected first, but it can be difficult to determine which leaves are most affected as symptoms rapidly spread to other leaves and the growing point (Photo 14).
- Leaves develop interveinal chlorosis and/ or white necrotic flecks and blotches.
- Leaves often kink, collapse and eventually die.

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71 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/detecting-and-managing-trace-element-deficiencies-in-crops

72 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

73 Reuter D. (2007). Trace element disorders in South Australian Agriculture. http://www.pir.sa.gov.au/__data/assets/pdf_file/0011/49619/Trace_Element_disorders_in_SA.pdf

74 GAJ, R. (2012). The effect of different phosphorus and potassium fertilisation on plant nutrition in critical stage and yield of winter triticale. *Journal of Central European Agriculture*, *13*(4).

75 DAFWA. (2016). Trace elements for high rainfall pastures. https://www.agric.wa.gov.au/soil-acidity/trace-elements-high-rainfall-pastures

76 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

- Tillering is reduced, with extensive leaf and tiller death. With extended deficiency, the plant may die.
- Surviving plants produce fewer and smaller heads.

Photo 13: *Patches of pale floppy plants in otherwise healthy crop.*

Source: DAFWA

Photo 14: *Middle leaves are affected first, showing yellowing and necrosis.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing zinc deficiency in wheat	Pale plants with interveinal chlorosis and kinked leaves	Differences include linear 'tramline' necrosis on zinc deficient plants. Manganese deficient plants are more yellow and wilted
Diagnosing nitrogen deficiency in wheat	Pale plants	Nitrogen deficient plants do not show wilting, interveinal chlorosis, leaf kinking and death
Diagnosing waterlogging in cereals	Pale plants	Waterlogged plants do not show wilting, interveinal chlorosis, leaf kinking and death
Diagnosing iron deficiency in cereals	Pale plants	New leaves are affected first and plants do not die
Diagnosing sulfur deficiency in cereals	Pale plants	New leaves are affected first and plants do not die

Managing Manganese deficiency

- Foliar spray.
- Acidifying ammonium nitrogen fertilisers can reduce manganese deficiency by lowering pH and making manganese more available to growing crops.
- Manganese fertiliser is effective but expensive as high rates and several applications are required to generate residual value.

- Seed manganese coating treatments have little effect in correcting the deficiency. [77]

Due to the detrimental effect of high soil pH on Mn availability, correction of severe Mn deficiency on highly calcareous soils can require the use of Mn-enriched fertilisers banded with the seed (three to five kg Mn/ha) as well as one to two follow up foliar sprays (1.1 kg Mn/ha). In the current economic climate growers on Mn-deficient country have tended not to use Mn-enriched fertilisers (due to their cost) but have relied solely on a foliar spray. This is probably not the best or most reliable strategy for long term management of the problem.

Neither soil nor foliar Mn applications have any residual benefits and must be re-applied every year. Another approach is the coating of seed with Mn. This technique is cheap and will probably be the most effective in conjunction with foliar sprays and/or Mn enriched fertilisers. Mn deficiency in lupins must be treated with a foliar spray at mid-flowering on the primary laterals. The use of acid fertilisers (e.g. nitrogen in the ammonium form) may also partially correct Mn deficiency on highly alkaline soils but will not overcome a severe deficiency.

Mn deficiency in crops can also be corrected by fluid application at seeding. [78]

5.8.2 Copper

Triticale is tolerant to low concentrations of available copper in soil, a condition widely associated with poor sandy soils in Australia. Such soils may contain enough total copper for tens of thousands of crops but it is relatively unavailable to widely grown cultivars of wheat, oats and barley. [79]

IN FOCUS

Tolerance of triticale, wheat and rye to copper deficiency and low and high soil pH

The tolerance of triticale to low copper status in a soil adjusted to extremes of pH was determined in pots in a glasshouse experiment, and compared with the tolerance of its parent species, wheat and rye. Wheat plants were extremely sensitive to copper deficiency at all soil pH values and failed to produce heads or grain, whereas rye produced maximum yield irrespective of copper status or soil pH. Intermediate tolerance of triticale was demonstrated by virtue of the copper-pH-genotype interaction in that triticale was tolerant like rye at pH 5.0, but sensitive at pH 8.4 like wheat.

Concentrations of copper were highest in rye and lowest in wheat, and decreased with increasing pH. The uptake of copper into grain and shoot was also lowest in wheat, and showed the same pH dependence as concentration. The appearance of copper deficiency symptoms on all plants which had low yields suggests that the major effect of pH in this system was on copper availability; the change in availability was, however, insufficient to affect the response of wheat (highly sensitive) or of rye which is highly tolerant. Triticale responded dramatically to the pH treatment and as predicted for such a hybrid was generally intermediate in tolerance to copper deficiency. [80]

77 DAFWA. Diagnosing manganese deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-wheat

78 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/detecting-and-managing-trace-element-deficiencies-in-crops

79 Graham, R. D. (1978). Tolerance of triticale, wheat and rye to copper deficiency.

80 Harry, S. P., & Graham, R. D. (1981). Tolerance of triticale, wheat and rye to copper deficiency and low and high soil pH. *Journal of Plant Nutrition*, *3*(1–4), 721–730.

Deficiency symptoms

Paddock

- Before head emergence deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green healthy crop (Photo 15).
- 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 copper deficiency before flowering is growing point death and tip withering, and/or bleaching and twisting up to half the length of young leaves (Photo 16).
- 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.
- Grain in less severely affected plants may be shrivelled. Heads with full grain droop due to weak stems.

Photo 15: *Pale necrotic flag leaf at head emergence.*

Source: DAFWA

Photo 16: *Partly sterile head and twisted flag leaf.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing false black chaff in wheat	Discouration on the upper stem and glumes	False black chaff does not affect yield or grain quality
Diagnosing molybdenum deficiency in cereals	White heads and shrivelled grain	Molydenum deficiency affects middle leaves first rather than the youngest leaf
Diagnosing boron deficiency in wheat	Youngest leaf death	Boron deficient plants are dark rather than light green and affected leaves have marginal notches and split near the base
Diagnosing stem and head frost damage in cereals	White heads, shrivelled grain, late tillers and delayed maturity	Spring frost does not cause death or twisting of the flag leaf and is location specific (frost-prone areas)
Diagnosing take-all in cereals	White heads and shrivelled grain	Take-all causes blackened roots and crowns and often kills the plant

Managing copper deficiency

- Foliar spray (only effective in the current season) or drilled soil fertiliser.
- Copper foliar sprays are not effective after flowering as sufficient copper is required pre-flowering for pollen development.

- Mixing copper throughout the topsoil improves availability due to more uniform nutrient distribution.
- As copper 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 copper 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. [81]

Traditionally, Cu deficiency has been corrected by applying Cu-enriched fertilisers and incorporating them into the soil. Most soils require 2 kg/ha of Cu to fully correct a deficiency, and this application may be effective for many years.

Due to the excellent residual benefits of soil-applied Cu, Cu deficiency in crops and pastures has been largely overcome in most areas from the use of the 'blue stone' mixes in the 1950s and 1960s.

However, Cu deficiency may be re-surfacing as a problem due to a number of reasons:

- The applications of Cu made 20–40 years ago may be running out
- The use of nitrogen fertilisers is increasing and they will increase the severity of Cu deficiency
- Cu deficiency is affected by seasonal conditions and farming practices (e.g. lupins in a lupin/wheat rotation make Cu deficiency worse in succeeding wheat crops).

Application of Cu by Cu-enriched fertilisers will currently cost approximately $19.00/ha. Cu deficiency in crops can also be corrected by fluid application at seeding with an application cost as low as $4.60/ha. Performance of soil applied Cu will improve with increased soil disturbance.

Although Cu deficiency is best corrected with soil applications, foliar sprays will also overcome the problem in the short term. A foliar spray of Cu (75–100 g/ha of Cu) is very cheap (approximately 90c/ha for the ingredient) but a second spray immediately prior to pollen formation may be necessary in severe situations. This was the case in a trial conducted on lower Eyre Peninsula in 2015, where a late foliar spray was necessary to completely eliminate Cu deficiency in an area that was extremely deficient for Cu and where the problem was exacerbated by a dry spring when wheat was forming pollen and setting grains. [82]

Although plants do have a requirement for copper, the main reason copper is applied is for the benefit of grazing stock. Copper deficiency is more common on light textured soils such as sands or sandy loams. Where required, copper is normally applied with the fertiliser at 1–2 kg/ha every 3–6 years. Inclusion of copper in the fertiliser will provide a long term supply to pasture and grazing stock. Where copper deficiency has been diagnosed in stock, more direct supplementation such as copper drenches are recommended. [83]

5.8.3 Zinc

Deficiencies of zinc are well known in all cereals and cereal-growing countries. Physiological evidence suggests that a critical level for zinc is required in the soil before roots will either grow into it or function effectively; it is likely the requirement is frequently not met in deep sandy, infertile profiles widespread in southern Australia.

81 DAFWA. Diagnosing copper deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-wheat

82 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/detecting-and-managing-trace-element-deficiencies-in-crops

83 Agriculture Victoria. (2008). Trace elements for dryland pastures.https://trove.nla.gov.au/work/32193714?q&versionId=39111757

Triticale is thought to have a high tolerance to Zinc (Zn) deficiency compared to wheat. The resistance index for Zn in triticale has been estimated at 75 per cent, second only to rye, which is a very resistant crop to Zn deficiency. [84]

In one experiment, Zn deficiency symptoms were either absent or only slight in triticale and rye, and occurred more rapidly and severely in wheats, particularly in durum wheats. In field experiments at the milk stage, decreases in shoot dry matter production due to Zn deficiency were absent in rye, and were on average 5 per cent in triticale, 34 per cent in bread wheats and 70 per cent, in durum wheats. Zinc fertilisation had no effect on grain yield in rye but enhanced grain yield of the other cereals. Zinc efficiency of cereals, expressed as the ratio of yield (shoot dry matter or grain) produced under Zn deficiency compared to Zn fertilisation were, on average, 99 per cent for rye, 74 per cent for triticale, 59 per cent for bread wheats and 25 per cent for durum wheats. [85]

Deficiency symptoms

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 17).
- Maturity is delayed. [86]

84 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

85 Cakmak, I., Ekiz, H., Yilmaz, A., Torun, B., Köleli, N., Gültekin, I., ... & Eker, S. (1997). Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. *Plant and Soil*, *188*(1), 1–10.

86 DAFWA. Diagnosing Zinc Deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

Photo 17: *Leaves yellow and die and can have tramline effect on leaves. Necrosis halfway along middle and older leaves causes them to droop.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing manganese deficiency in wheat	Leaf kinking, pale lesions, streaks and wilted plants	Manganese deficient plants are very pale, are more common as patches of limp dying plants and lack the parallel necrotic tramlines adjoining the midrib
Diagnosing wheat streak mosaic virus	Stunted plants with many tillers and striped leaf lesions	Zinc deficient plants have pale linear spots or lesions that can develop into parallel 'tramlines' and lack vivid yellow streaks towards the leaf tip
Diagnosing yellow dwarf virus	Stunted plants with many tillers and striped leaf lesions	Zinc deficient plants have pale linear spots or lesions that can develop into parallel 'tramlines' and lack vivid yellow streaks towards the leaf tip

Managing Zinc deficiency

- 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 zinc is immobile in the soil topdressing is ineffective, only being available to the plant when the topsoil is wet.
- Mixing zinc throughout the topsoil improves availability due to more uniform nutrient distribution.

- Zinc drilled deep increases the chances of roots being able to obtain enough zinc 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. [87]

Zinc may be required on light textured soils such as sands or sandy loams and particularly those that are alkaline. The more alkaline the soil, the lower the availability of zinc for plant uptake. Zinc responses on pasture are rare, but where required zinc should be applied at about 1–2 kg/ha, every 5–6 years. [88]

Correction of Zn deficiency in a way which provides benefits after the year of treatment is possible through the use of Zn-enriched fertilisers or a pre-sowing spray of Zn onto the soil (incorporated with subsequent cultivations). There is also the option of a Zn-coated urea product which can be used to supply Zn to the crop, and is most useful when pre-drilling urea before the crop.

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

Only Zn-enriched fertilisers of the homogenous type (fertiliser manufactured so that all granules contain some Zn) are effective at correcting Zn deficiency in the first year of application. A rate of two kilograms of elemental Zn per hectare applied to the soil is necessary to overcome a severe Zn deficiency and should persist for three to ten years (depending on soil type). Short intervals between repeat applications of Zn will be necessary on heavy and calcareous soils in the high rainfall areas, while seven to ten year intervals will be acceptable in the low rainfall areas. Following an initial soil application of 2 kg Zn /ha repeat applications of 1 kg/ha will probably be sufficient to avoid the reappearance of Zn deficiency in crops and pastures. Most zinc-enriched fertilisers are now not sold as pure homogeneous types, but providing a homogeneous fertiliser is used as part of the mix then the final product is still satisfactory for correcting Zn deficiency. For example, the company may produce a diammonium phosphate (DAP) Zn five per cent ‘parent’ product which has Zn on every granule which they will then blend with straight DAP to give 1 and 2.5 per cent products for the retail market. This option will currently cost approximately $17.00/ha.

Zn deficiency can be corrected in the year that it is recognised with a foliar spray of 250–350 g Zn/ha but it has no residual benefits and is therefore not the best approach for a long-term solution. This option will currently cost approximately $1.00/ha (plus the cost of the operation). Zinc can be mixed with many herbicides and pesticides but not all, so check with your supplier for compatible tank mixes before you make the brew. Recent trials in eastern Australia suggest that chelated sources of trace elements are no more effective at correcting a deficiency than their sulphate cousin, although older results from WA showed that there are situations where they can be superior.

Seed dressings of zinc are another option for managing Zn deficiency. These products are effective and will supply Zn to the young crop but they will not completely overcome a severe deficiency. Nor will they increase soil reserves of Zn. Seed with high internal levels of Zn can also be used in a similar way. However, both approaches should be used in conjunction with soil applications to correct and manage Zn deficiency in the long term. This option will currently cost approximately $3.00/ha. [89]

87 DAFWA. Diagnosing Zinc Deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

88 Agriculture Victoria. (2008). Trace elements for dryland pastures. https://trove.nla.gov.au/work/32193714?q&versionId=39111757

89 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/detecting-and-managing-trace-element-deficiencies-in-crops

5.8.4 Iron

Iron is involved in the production of chlorophyll and is a component of many enzymes associated with energy transfer, nitrogen reduction and fixation and lignin formation. Iron deficiencies are mainly manifested by yellow leaves due to low levels of chlorophyll. Leaf yellowing first appears on the younger upper leaves in interveinal tissues. Severe iron deficiencies cause the leaves to turn completely yellow or almost white, and then brown as leaves die. Iron deficiencies are found mainly in alkaline soils, although some acidic, sandy soils, low in organic matter, may also be iron deficient. Cool, wet weather enhances iron deficiencies especially in soils with marginal levels of available iron. Poorly aerated or compacted soils also reduce iron uptake. High levels of available phosphorus, manganese and zinc in soils can also reduce iron uptake. [90]

Symptoms

Paddock

- Pale plants particularly in waterlogged or limed areas (Photo 18).

Plant

- Youngest growth is affected first and most severely.
- Symptoms begin with young leaves turning pale green or yellow.
- Inter-veinal areas become yellow and in severely deficient plants the inter-veinal area turns almost white (Photo 19).
- New growth remains yellow for some time before leaves start to die.
- Old leaves remain pale green and apparently healthy.
- Severely affected plants are stunted with thin spindly stems.

Photo 18: *Pale green to yellow plants.*

Source: DAFWA

90 Schlegel, R. H. (2013). *Rye: genetics, breeding, and cultivation*. Crc Press.

Photo 19: *Pale yellow, iron deficient leaves, most showing prominent green veins (right) compared with dark green healthy leaf (left).*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing sulfur deficiency in cereals	Pale plants with pale new growth	Sulfur deficient plants do not have interveinal chlorosis
Diagnosing group B herbicide damage in cereals	Pale seedlings with interveinal chlorosis on new leaves	Herbicide damaged plants generally recover and are not restricted to waterlogged areas
Waterlogging, nitrogen, molybdenum and manganese deficiency	Pale growth	However middle or older leaves are affected first

Managing iron deficiency

- No yield responses to iron to justify soil application.
- Where symptoms occur, particularly in cold and wet conditions, they are frequently eliminated by increased soil and air temperatures.
- Foliar sprays will remove the symptoms where they occur in highly calcareous or limed soils. [91]

5.9 Nutritional deficiencies

Many soils in the cropping zone of south-western Australia are deficient in macro and micronutrients in their native condition. To help identify nutritional deficiencies, see the GRDC Winter Cereal Nutrition: the Ute Guide.

MORE INFORMATION

Crop nutrition Factsheet

Detecting and managing trace element deficiencies in crops

91 DAFWA. Diagnosing iron deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-cereals