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GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

TRITICALE

SECTION 5

NUTRITION AND FERTILISER

DECLINING SOIL FERTILITY | CROP REMOVAL RATES | SOIL TESTING | PLANT-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, 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.
- Triticale has higher nutrient uptake efficiency than other crops.
- 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%.
- Triticale has similar phosphorus and nitrogen requirements as wheat and responds to most compound fertilisers.
- In South Australia, high rates of fertiliser applied to triticale on sandy country have resulted in increased yields.
- Southern Australian cropping soils are more likely to be deficient in zinc (Zn), copper (Cu), and manganese (Mn) than the other trace elements.
- Triticale grows productively on alkaline soils where certain trace elements are deficient for other cereals.

Triticale has a very extensive root system (Photo 1) and can mine the soil more efficiently than other cereals where fertility is poor. [1] In general, triticale will respond favourably 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 than wheat when given larger increments of nitrogen and phosphorus inputs. [2]

1 Mergoum et al. (2004) In S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

2 S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, 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.*

Photo: Osborne Seed Company Variety Trials

5.1.1 Declining soil fertility

The natural fertility of cropped agricultural soils in Australia is declining over time. Grain growers must continually review their soil-management programs to ensure the long-term sustainability of high-quality grain production (see Photo 2). [3] Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils.

Although crop rotations with grain legumes and ley pastures help maintain and improve 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.

3 Joint FAO–IAEA Programme (n.d.) Crop nutrition: resilience to harsh environments. Joint FAO–IAEA Programme, http://www-naweb.iaea.org/nafa/swmn/topic-crop-nutrition.html

Photo 2: *Without adequate effort to maintain the fertility of the soil, cereal plants will struggle, such as these in an infertile paddock.*

Source: Joint FAO–IAEA Programme

Balancing sources of nutrition

The yield 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. [4]

To obtain the maximum benefit from investment, fertiliser programs must provide a balance of required nutrients. For example, here is little point in applying enough nitrogen (N) if phosphorous (P) or zinc (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 will assist in identifying factors such as water stress, P or Zn deficiency, disease, or other management practices responsible for reducing yield. [5]

5.1.2 Fertilisers

Successful fertiliser decisions require robust information about a crop's likely yield response to that nutrient in a specific soil type, also taking into account the paddock history and season. 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. [6]

Triticale has similar phosphorus and nitrogen requirements as wheat and responds well to most compound fertilisers. Zinc has also been found a valuable added nutrient for Mallee sowings. [7]

- In South Australia, high rates of fertiliser applied to triticale on sandy country have resulted in increased yields. [8]

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

5 DAF Qld (2010) Overview [of nutrition management]. DAF Qld, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

6 Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

7 Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

8 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, http://www.farmtrials.com.au/trial/13801

In trials in NSW, researchers tested the response of triticale varieties to N and P application. Soil tests indicated marked differences between the years in N and P status. In 2002, the site had a very low soil N level (2 µg/g nitrate) and a low/ medium level of P (16 µg/g available P). The data from the 2004 site indicated much higher levels of nutrients, 64 µg/g nitrate and 46 µg/g phosphorus. Although 2004 experiment used varieties that have now been largely superseded, the major findings remain relevant: that, in a high-rainfall region with yield potential levels above average, the yield responses to N fertiliser of a range of triticale varieties is at least equal to those for wheat (Table 1). With high yield potential (up to 8 t/ha) triticale varieties showed up to four 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 (t/ha) to nitrogen fertiliser.* [9]

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 greater 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, availability of water to the crop, 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 P and 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/ha at sowing. This is equivalent to 75–100 kg MAP per ha which will also include 7.5–10 kg N/ha. A triticale used for grazing as well as grain production will require significant N. If targeting 3 t/ha then a minimum of 69 kg N/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 after grazing or during the stem-elongation stage (soon after the Zadoks growth stage 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 [12] lists the concentrations 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/ha this could be achieved by applying:

- 100 kg MAP per ha or 10 kg N per ha, plus

9 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

10 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

11 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

12 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

- 130 kg urea per ha or 59.8 kg N per ha supplying a total of 69 kg N per ha for the season.

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 Company

In a field experiment conducted in India, nine combinations of N and 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 over-fertilisation. 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. [13]

Application

Application method

Apply by using either gravity feed openers or air drills to the bury the fertiliser in a sub-surface band 5 cm 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, as the concentration of fertiliser around the seed is increased.

Rates may be increased by 50% when using air seeders 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. [14]

MORE INFORMATION

Crop nutrition: region by region

5.1.3 Fungi and soil health

Arbuscular mycorrhiza (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 take up 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 intake and growth. A plant's root system, however big, can never be as extensive as the network of fungal fibres.

13 S Moinuddin, MMRK Afridi (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.

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

In cropping systems, most plants depend, to varying degrees, on mycorrhizal fungi to supply them with nutrients such as phosphorus and zinc. (By comparison, saprobic soil fungi, which colonise and break down organic matter, and do not require a host plant to complete their lifecycle.) In return, the plant hosts the fungus and supplies it with carbohydrates. AMF is therefore known as an obligate symbiont. It produces spores as a means of survival in soil during the absence of a host (e.g. during a clean fallow) and then germinates and colonise host roots once plants grow again.

This mutually beneficial partnership 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, resulting vegetation in these environments to struggle.

AMF levels can be severely reduced by long periods of fallow, such as those induced by drought. 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 also be reduced by the growth of non-host crops.

Primarily, LFD leads to a phosphorus or zinc deficiency of the plant; this 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 it is 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 supported by AMF.

When reintroduced to the soil, the arbuscular 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. [15]

In one study, the colonisation of rye roots with arbuscular mycorrhizal fungi was investigated at two sites, cultivated using conventional or biological-dynamic farming methods. The AMF infection rate and infected root length were significantly higher at the biologically-dynamic cultivated site. It was suggested that these differences are due to several factors, such as the use of fertilisers and agro-chemicals, and the influence of crop rotation. [16]

Management to optimise mycorrhizae

If you suspect low numbers of AMF in your paddock:

- Grow crops with low or very low mycorrhizal dependency, e.g. wheat or barley, as they won't suffer much yield loss but will still increase the AMF inoculum for following crops.
- Avoid non-mycorrhizal crops, as they will not increase AMF inoculum status.
- If you wish to grow a crop that is highly dependent on AMF (e.g. to get a good price for your grain), apply high rates of P and Zn fertilisers.
- Adopt zero- or reduced-tillage practices during fallow periods, as this is less harmful to AMF than frequent tillage. [17]

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15 N B (2009) Mycorrhizae and their influence on P nutrition. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2009/09/Mycorrhizae-and-their-influence-on-P-nutrition

16 B Sattelmacher, S Reinhard, A Pomikalko (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.

17 N Seymour (2009) Mycorrhizae and their influence on P nutrition. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2009/09/Mycorrhizae-and-their-influence-on-P-nutrition

5.2 Crop removal rates

Each tonne of triticale harvested will remove approximately 23 kg N/ha from the paddock (Table 3). So, if targeting 3 t/ha then a minimum of 69 kg N/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). [18]

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

5.3 Soil testing

Key points:

- The 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 nutrients, crops and soil class.
- A soil test value indicates if there is sufficient nutrient supply to meet the crop's demand.
- Results from more than 2,200 trials in south-east Australia have been compiled into a database that can be used to estimate soil test critical values and ranges.
- A value above the critical range indicates there is not likely to be a crop yield response to added nutrients.
- A value below the critical range indicates there is likely to be a crop yield response to added nutrients.
- Critical ranges for particular crops and soils have been established for a depth of 0–10 cm.
- Soil sampling to greater depth (0–60 cm) is considered important for more mobile nutrients (N, K and S) as well as for pH, salinity and sodicity.
- Use local data and support services to help integrate soil test data into making profitable fertiliser decisions.

In south-eastern Australia profitable grain production depends on applied fertilisers, particularly nitrogen (N) and phosphorus (P), and to a lesser extent, potassium (K), sulfur (S), zinc (Zn), manganese (Mn) and copper (Cu).

Fertiliser is a major cost for grain growers, so making careful selections of crop nutrients is a major determinant of profit. Both under-fertilisation and over-fertilisation can lead to economic losses, due to unrealised crop potential or wasted inputs.

Before deciding on how much fertiliser to apply, it is important to understand the quantities of available nutrients in the soil, where they are located in the soil profile and the likely demand for nutrients in that season.

The values from appropriate soil tests can be compared against critical nutrient values and ranges; these indicate which nutrients are limiting and which are adequate.

Soil test critical values advise growers if a crop is likely to respond to added fertiliser, but without further information, they do not predict optimum fertiliser rates.

18 Agriculture Victoria (2008) Establishing forage cereals. Note AG1269. Revised. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/forage-cereals/establishing-forage-cereals

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

5.3.1 Why test soil?

Soils are tested for several reasons, but the principal ones are:

- to estimate how much water can be stored;
- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity) and salinity, acidity, or high levels of boron or aluminium which affect the crop demand as well as the ability to access nutrients;
- the occurrence of soil-borne diseases;
- 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. [19]

5.3.2 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 use a representative sample of soil.
2. To analyse the soil using the accepted procedures that have been calibrated against fertiliser experiments in that region.
3. To interpret the results using criteria derived from those calibration experiments.

As each of these steps may be under the control of a different person or entity, it is important to use standardised procedures to that results are accurate. 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. [20]

MORE INFORMATION

Soil nutrient testing: How to get meaningful results

5.3.3 Types of test

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

- bicarbonate extractable P (Colwell-P);
- diffusive gradients in thin-films (DGT);
- 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 can be unreliable. This is because soil nitrogen availability and crop demand for nitrogen are both highly influenced by seasonal conditions. Ideally, soil testing for N should be carried out as close to sowing as possible, allowing for results to be returned.

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, or PBI),

19 GRDC (2014) Soil testing for crop nutrition, southern region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingS

20 D Loch (n.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

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MORE INFORMATION

Soil testing for crop nutrition—southern region

electrical conductivity (EC), and chloride and exchangeable cations (CEC) including aluminium. [21]

5.4 Plant-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.

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. This is an unseen factor in plant growth—until imbalances become so severe that visual symptoms appear on the plant. The only way to know whether a crop is adequately nourished before this stage is to have the plant tissue analysed during the growing season.

5.4.1 Plant tissue analysis

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 of nutrients may also 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.

Although a plant-tissue analysis can pinpoint the cause of nutritional imbalances, there is little point in using it if the plants come from fields that are infested with weeds, insects, or disease organisms, if they are stressed for moisture, or if they have some physical injury.

Sampling a crop periodically during the season or once a year provides a record of its nutrient content that can be used through the growing season or from year to year. Armed with soil-test information and a plant-analysis report, a producer can closely tailor fertiliser practices to specific soil and plant needs.

Things to do when sampling:

- Sample the correct plant part at the specified time or growth stage.
- Use clean plastic disposable gloves to sample to avoid contamination.
- Sample tissue (e.g. entire leaves) from vigorously growing plants unless otherwise specified in the sampling strategy.
- Take a sufficiently large sample quantity (adhere to guidelines for each species provided).
- When troubleshooting, take separate samples from good and poor growth areas.
- When necessary, wash samples while fresh 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.

Things to avoid when sampling:

- 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 by dust, fertilisers, chemical sprays, perspiration and sunscreen.
- Avoid atypical areas of the paddock, e.g. poorly drained areas.
- Do not sample plants of different vigour, size and age.

21 GRDC (2014) Soil testing for crop nutrition, southern region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingS

- Do not collect 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. [22]

Table 4: *Plant tissue requirements for nutrient testing of triticale.*

Growth stage to sample	Plant part	Number required
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 (GS 2131)	Youngest expanded blade (YEB) plus next 2 lower blades	40

Source: Back Paddock Company

5.5 Nitrogen

Key points:

- Nitrogen (N) is needed for crop growth in larger quantities than any other nutrient.
- Nitrate (NO3-) is the highly mobile form of inorganic nitrogen in both the soil and the plant.
- Sandy soils in high-rainfall areas are most susceptible to nitrate loss through leaching.
- Soil testing and nitrogen models will help determine seasonal nitrogen requirements.
- Some farmers believe that triticale produces more grain under the same amount of applied nitrogen as wheat and barley. [23]

The two forms of soil mineral N absorbed by most plants are nitrate (NO3N) and ammonium (NHþ4N) (Figure 1). [24] In well-aerated soils during the growing season nitrate becomes the main form of N available for crops as microbial activity quickly transforms ammonium into nitrate. It is crucial to keep nitrate at an adequate level because, on one hand, if they are too low crop production will be limited and, on the other hand, if they are too high environmental pollution can result. The levels of soil nitrate vary across space and over time. Proper agricultural management needs to consider both site-specific variations as well as temporal patterns in soil nitrate to supply optimum amounts from both organic and mineral sources. [25]

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

23 GRDC (2006) Triticale. Ground Cover. No. 59, 1 January 2006. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-59/Triticale

24 Soilquality.org. Nitrogen: NSW. Factsheet. Soilquality.org, http://www.soilquality.org.au/factsheets/nitrogen-nsw

25 M Ladoni, AN Kravchenko, GP Robertson (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. PLOS ONE, 10 (11), e0143358.

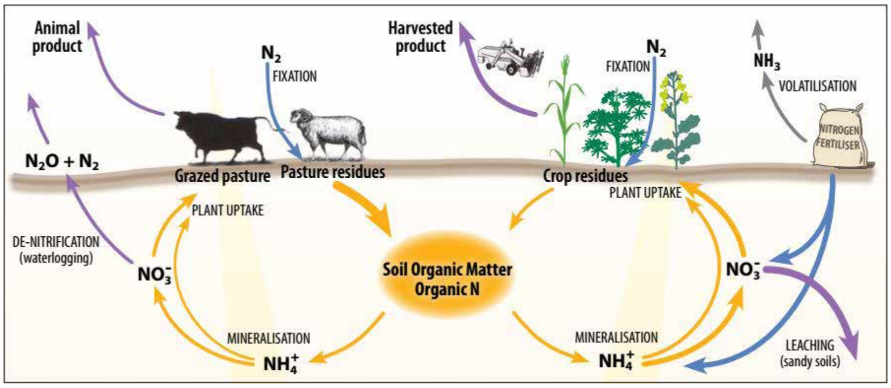

Figure 1: *Principle nitrogen cycling pathways in a mixed cropping/pasture system (adapted from Peverill et al. 1995).*

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. They also 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 2). [27]

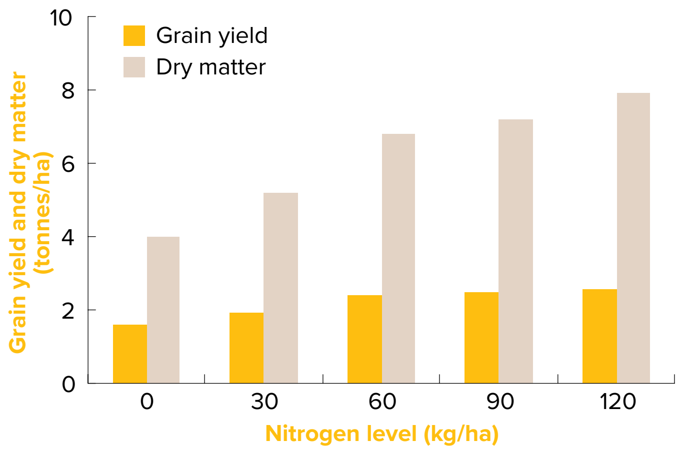

Figure 2: *Triticale grain yield and straw dry-matter response to nitrogen levels under drought conditions in Morocco.*

Source: Mergoum and Gómez-Macpherson 2004

In trials in Europe, researchers found an N rate of 90–120 kg/ha to be economically and ecologically optimal for spring triticale. It resulted in the highest (4.81–4.92 Mg/ ha-1) grain yield. [28]

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

27 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

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

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

Pre-plant N has been found to increase forage production and produce more boot-stage triticale biomass. It also tended to increase P uptake, but in some cases, can reduce P and forage protein concentrations, likely due to plant dilution. [29]

Trials outside Canberra exploring crop management of dual-purpose cereals suggest that N should be applied at sowing to ensure good early plant growth and to build up a feedbank. Post-sowing nitrogen application should be left until after grazing: it 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. Immediately after grazing finishes, growers may safely apply 50 kg/ha of nitrogen as urea to boost plant recovery. [30]

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. [31]

IN FOCUS

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

Researchers conducted a field experiment at Mintaro, South Australia, on triticale and three other grains to learn more about how they respond to N fertiliser. They planted a hexaploid triticale from Mexico and local cultivars of wheat, rye and barley. To each they applied five levels of fertiliser nitrogen (0, 35, 70, 105 and 140 kg/ha) with four replications.

There was a visually discernible response to nitrogen fertiliser by all four genotypes from an early stage, and this confirmed by quantitative sampling at the stages of tillering, anthesis and maturity. Responses in plant dry weight to 105 kg N/ha were maintained until anthesis, but grain yield only improved significantly at 35 kg N/ha. Total dry-matter production responses at maturity to more than 35 kg N/ha were small. The numbers of tillers and heads were increased by adding nitrogen up to 140 kg/ha for tillering, and 105 kg/ha for heads. Plant height increased with the application of up to 70 kg/ha, but greater amounts of N than this resulted in significant lodging in both 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 /ha, respectively. Nitrogen supply had little effect on maturity: plants at 0 kg/ha and 140 kg/ha of N reached anthesis less than a day apart. The lack of a significant nitrogen × genotype interaction in nearly all the data suggests that the triticale is the same as the traditional cereals in it nitrogen needs.

29 B Brown (2011) Nitrogen timing for boot stage triticale forage yield and phosphorus uptake. Forage and Grazinglands, 9 (1), 62–67.

30 D Lush (2014) Rules of thumb for grazing cereals. Ground Cover. No. 109, March–April 2014. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-109-Mar-Apr-2014/Rules-of-thumb-for-grazing-cereals

31 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Triticale consistently out-yielded 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 lowest in the rye, the latter also being the least responsive to nitrogen.

The advantage of the triticale lay in its high grain protein and lysine content, combined with good yield. [32]

5.5.1 Symptoms of deficiency

Most of the deficiency symptoms listed are based on observations in wheat and other cereals. Specific information for triticale is limited. Observing these symptoms should prompt growers to investigate further.

What to look for in the paddock

- Light green to yellow plants particularly on sandy soils or unburnt header or swathe rows (Photo 3). [33]
- Double-sown areas have less symptoms if nitrogen fertiliser was applied at seeding.

What to look for in the plant

- Plants are pale green with reduced bulk and fewer tillers.
- Symptoms first occur on the oldest leaf, which becomes paler than the others and shows marked yellowing starting at the tip and gradually merging into light green (Photo 4).
- Other leaves start to yellow, and the oldest leaves change from yellow to almost white.
- Leaves may not die for some time.
- Stems may be pale pink.
- Plants develop more slowly than healthy plants, but maturity is not greatly delayed.
- Reduced grain yield and protein levels.

32 RD Graham, PE Geytenbeek, BC Radcliffe (1983) Responses of triticale, wheat, rye and barley to nitrogen fertiliser. Animal Production Science, 23 (120), 73–79.

33 DAFWA (2015) Diagnosing nitrogen deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-wheat

Photo 3: *Nitrogen deficiency on unburnt header row.*

Source: DAFWA

Photo 4: *Deficient plants are smaller with yellow leaves and fewer tillers.*

Source: DAFWA

What else it could be

Before assuming nitrogen deficiency, eliminate other possible causes of symptoms (Table 5).

Table 5: *Other possible problems of triticale that could be confused for nitrogen deficiency.*

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

Source: DAFWA

VIDEOS

WATCH: GCTV14: Nitrogen deficiency

5.5.2 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: the greatest risk is with urea, and lower, but still significant, with a solution of urea and ammonium nitrate (UAN) and ammonium sulphate. [34]

Nitrogen fertilisers are a significant expense for broadacre farmers, so optimising the use of fertiliser will 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.

Deficiency symptoms can be treated with N fertiliser or foliar spray. Note that, when topdressing on dry, alkaline soils in dewy conditions, there is a risk of volatilisation loss from urea or ammonium sources of nitrogen. Losses rarely exceed 3% per day. [35]

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 cereal 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, around 3–4 weeks after germination.

Later nitrogen applications can also have yield benefits by aiding increased tiller survival, leaf duration and photosynthetic area. However, delaying application reduces the chance that economic gain from the response to nitrogen will be

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

35 DAFWA (2015) Diagnosing nitrogen deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-wheat

achieved. An advantage of late applications (once the first node is visible) is that growers have a better idea of what the yield might be 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 6 shows the N required for different yield and protein combinations at maturity and anthesis. [37] 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. [38]

MORE INFORMATION

Yield Prophet®

Table 6: *Nitrogen requirements for cereal crops at different combinations of yield and grain protein at maturity, and the corresponding N required at anthesis.*

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

Source: GRDC

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.

5.6 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.

36 R Quinlan, A Wherrett (2013) Nitrogen: NSW. Soilquality.org.au

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

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

- 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; i.e., it is higher yielding than other cultivars under low P supply. It has also been classified as phosphorus-responsive; i.e. it is higher yielding than other cultivars under high P supply). [39]

After nitrogen stress, phosphorus is the second most widely occurring nutrient deficiency in cereal systems around the world. [40] Phosphorus is essential for plant growth, but few Australian soils have enough P 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 P applied to the soil, with many soils able to adsorb or 'fix' phosphorus, making it less available to plants (Figure 3). [41] A soil's ability to fix phosphorus must be measured when determining requirements for crops and pastures. [42]

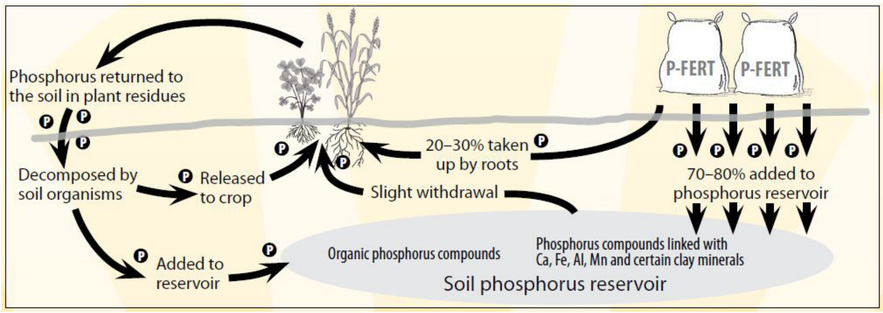

Figure 3: *The phosphorus cycle in a typical cropping system is particularly complex, because movement through the soil is minimal and availability to crops is severely limited.*

Source: Soilquality.org

IN FOCUS

Cereal types and phosphorus use in Waikerie, Murray Mallee

Crop growth on the flats is typically thicker than on sand hills, but in most years grain yields are less. Soil P levels (0–10 cm) do not vary markedly across the different soil types: 19 ppm for soil in the flats, 17 ppm on the slopes and 11 ppm in the sand hills.

Researchers wanted to test the concept of reducing rates where the crop is likely to yield lower, and possibly increasing them where the crop is likely to yield more. GRDC funded a project to investigate this. The researchers applied different P treatments in 2005 and 2006 to crops on the flats and in the sand hills. As well, in 2005, thy also tested the value of growing a different cereal crop on the flats (triticale) compared with the sand hill (barley).

In 2005, grain yield responses to applied P were greater in the lighter soil zone (sand hills) than in the heavier soil zone (flats). The most economic rate for both zones was 3 kg/ha. A higher rate of P (11 kg/ha) increased grain yield on the lighter soil (Zone 2) more than on the heavier shallow

39 JI Ortiz-Monasterio, RJ Pena, WH Pfeiffer, AH Hede (2002) Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In Proceedings of the 5th International Triticale Symposium, Annex, 30 June–5 July. Vol. 30.

40 JI Ortiz-Monasterio, RJ Pena, WH Pfeiffer, AH Hede (2002) Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In Proceedings of the 5th International Triticale Symposium, Annex, 30 June–5 July. Vol. 30.

41 Soilquality.org. Phosphorus: Queensland. Factsheet. Soilquality.org, http://www.soilquality.org.au/factsheets/phosphorus-queensland

42 Soilquality.org. Phosphorus: NSW. Soilquality.org.au.

soil (Zone 1). This is consistent with lower leaf tissue P from the crop on the sand hill (3,000 mg/kg) than on the flat (3,700 mg/kg).

In this trial the grain yield of triticale was the same on the flats (1.3 t/ha) as on the sand hill, while the barley grain yield was similar on the flats (1.47 t/ha) and the sand hill (1.48 t/ha).

In 2006, grain-yield responses of barley and triticale to different rates of P and N fertiliser were compared for three different zones (flat, slope and hill) in this paddock. In each zone, two rates were compared, one rate for an average year and a lower rate. [43]

As in 2005, grain yields were lower on the flats than on the sand hills. However, in these lower-yielding crops grain yield responses to P and N were relatively small. In only two cases for triticale (on the flats and in the hills) did yield increases cover the cost of the extra fertiliser (0.07 t/ha) within a zone, and in one case (on the slopes) for the barley (0.06 t/ha).

While there has been substantial improvement (e.g. through genetic gains) in terms of P responsiveness in triticale, there has been little improvement in terms of phosphorus-use efficiency, i.e. performance in low-phosphorus conditions. Researchers in Mexico found that triticale was responsive to P applications, with grain yields in some genotypes almost three times higher in the application of P formulated as P2O5 applied at a rate of 80 kg. [44]

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. [45]

Triticale responds well to phosphorus application under drought conditions (Figure 4). [46]

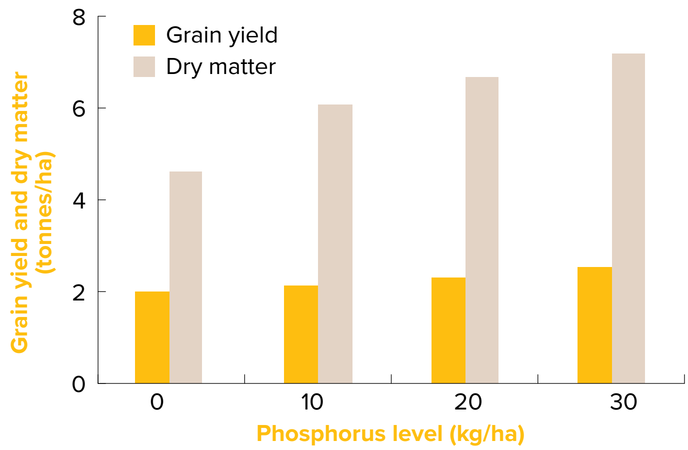

Figure 4: *Triticale grain yield and straw dry-matter response to phosphorus levels under drought conditions in Morocco.*

Source: Mergoum and Gómez-Macpherson 2004

43 A Mayfield (n.d.) SPA00003: Improvement of nutrient management through effective use of precision agriculture technologies in the southern Australian grains industry. Final reports. GRDC, http://finalreports.grdc.com.au/SPA00003

44 JI Ortiz-Monasterio, RJ Pena, WH Pfeiffer, AH Hede (2002) Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In Proceedings of the 5th International Triticale Symposium, Annex, 30 June–5 July. Vol. 30.

45 B Iqbal, B Ahmad, I Ullah, AA Khan, S Anwar, A Ali, K Shahzad, S Khan (2016) Effect of phosphorus, sulfur and different irrigation levels on phenological traits of Triticale. Pure and Applied Biology, 5 (2), 303–310.

46 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

Another study found that, under field conditions, triticale presented higher grain yield response to P than seven wheat cultivars did. [47]

A study in south-western Australia found that on an acidic soil, triticale required from 50–70% less P than wheat, but on less acidic soil it required 100% more P. [48]

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

In sandy soils P has a tendency to leach out of the soil. Sandy soils have been measured to lose up to 100% of applied phosphorus to leaching in the first season. Certainly 50% losses are common. However, 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 P 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.

Phosphorus deficiency is thought to be responsible for biomass reduction of triticale in nutrient solution with aluminium. One study suggests that in previous experiments, P deficiency was probably the most important limiting factor in acid nutrient solutions with aluminium. [49]

5.6.1 Symptoms of deficiency

What to look for in the 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 5). [50]
- Affected areas are more susceptible to leaf diseases.

What to look for in the plant

- In early development, usually in cases of induced phosphorus deficiency, seedlings appear to be pale olive green and wilted (Photos 6 and 7).
- 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 with 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. By 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.

47 JR Ben (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 October 1990.

48 MDA Bolland (1992) The phosphorus requirement of different crop species compared with wheat on lateritic soils. Fertilizer Research, 32 (1), 27–36.

49 VL Quartin, HG Azinheira, MA Nunes (2001) Phosphorus deficiency is responsible for biomass reduction of triticale in nutrient solution with aluminum. Journal of Plant Nutrition, 24 (12), 1901–1911.

50 DAFWA (2015) Diagnosing phosphorous deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-wheat

Photo 5: *Stunted early growth with reduced tillers in P deficient crop on the left.*

Source: DAFWA

Photo 6: *P-deficient plants on the left are later maturing with fewer and smaller heads.*

Source: DAFWA

Photo 7: *Dark leaves with necrosis moving down from the tip of the oldest leaf is symptom of P deficiency.*

Source: DAFWA

What else it could be

Before assuming phosphorous deficiency, eliminate other possible causes of symptoms (Table 7).

Table 7: *Other possible problems of triticale that could be confused for phosphorous deficiency.*

Condition	Similarities	Differences
Nitrogen deficiency	Small, less tillered and light green plants	Phosphorus-deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing
Molybdenum deficiency	Small, less tillered and light green plants	Phosphorus-deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing
Potassium deficiency	Small, less tillered and light green plants	Phosphorus-deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing

Source: DAFWA

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

Phosphorus does leach on sands with a very low PBI (a measure of phosphorus retention), particularly on coastal plains. Topdressing is effective on these soils. [51]

Soil testing

Testing the phosphorus levels in your soil is important and will help in the budgeting of your phosphorus dollar. 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 or 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 P may be extracted from the soils. This 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. [52]

5.6.2 Managing phosphorus

Key points:

- After decades of consistent 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 show that levels are adequate.
- Work with an adviser to refine your fertiliser strategy.
- Adding fertiliser to the topsoil in systems that rely on stored moisture does not always place nutrients where crop needs them.
- Testing subsoil (10–30 cm) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Applying P at depth (15–20 cm deep on 50 cm bands) can improve yields over a number of cropping seasons (if other nutrients are not limiting).
- Addressing low P levels will usually increase potential crop yields, so match the application of other essential nutrients, particularly N, to this adjusted yield potential. [53]

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, and potentially reduce yield. [54]

Phosphorus fertiliser and, where necessary, nitrogen fertiliser are recommended in the same amounts as recommended for wheat. The current recommendations for the Mallee are:

- Phosphorus at 10–15 kg/ha and 10–20 kg/ha of nitrogen applied at sowing.

MORE INFORMATION

Phosphorus in the southeast soils

Crop nutrition: Phosphorus management—southern region

51 DAFWA (2015) Diagnosing phosphorus deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-wheat

52 G Bailey, T Brooksby (n.d.) Managing phosphorous in south-east soils. South East Soil Issues, http://www.naturalresources.sa.gov.au/southeast/land/soil-management/South-East-Soil-Issues

53 GRDC (2012) Phosphorus management, southern region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-PhosphorusManagement

54 Alberta Agriculture and Forestry (2016) Fall rye production. Agdex 117/20-1. Revised. Alberta Government, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

VIDEOS

WATCH: GCTV13: Phosphorus uptake

WATCH: Improving phosphate use efficiency

Occasionally nitrogen may need to be broadcast after sowing if the crop appears deficient. [55]

Arbuscular mycorrhizae fungi play an important role in plant uptake of P. The uptake of this nutrient by wheat, rye, and triticale was, respectively, 10%, 64%, and 35% higher with AMF infection than without. Triticale followed wheat, with similar mycorrhizal dependency. [56]

5.7 Sulfur

Key points:

- In cereals, lower sulfur levels lead to lower protein and because this affects the quality of the flour, the price received for this grain will be reduced.
- The leaves on deficient plants leaves turn pale with no stripes or green veins, but generally do not die although growth is retarded and maturity delayed
- Top-dressing 10–15 kilograms per hectare of sulfur as gypsum or ammonium sulphate will overcome deficiency symptoms.
- Comprehensive research in terms of triticale and sulfur are limited.

Sulfur is a major plant element. It is an essential plant nutrient (along with N) required for the production of amino acids, which in turn make up proteins. In cereals, lower sulfur levels lead to lower protein and because this affects the quality of the flour, the price received for this grain will be reduced. A lack of sulfur will also affect the oil content and hence the price received for canola.

Yield losses also occur in low-sulfur situations, especially with canola. Ideally, plants will take up sulfur at the same levels as phosphorus.

Sulfur is present to varying degrees in nearly all soils. Soils with clay and gravel have generally more sulfur present than sandier soils from high-rainfall areas. This is due in part to the composition of the original parent rock. Organic sulfur, which is mineralised into plant-available sulfate, is more prevalent in soils with high clay and gravel content. The sandier soils from higher-rainfall areas do not have any ability to restrict the leaching of water-soluble sulfate. Sulfur remaining in plant residues is readily recycled into the soil. [57]

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 triple superphosphate (TSP), mono-ammonium phosphate (MAP) and diammonium phosphate (DAP), which are low in S. Sulfur, like Nitrogen, is also subject to leaching and in wet seasons may move beyond the root zone.

The 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 . [58]

The forage production of triticale and wheat is essential to many livestock producers. Very little data is available concerning the effects of sulfur fertilisation on production and quality of triticale or wheat forage. However, research conducted in a greenhouse may give clues to the use of S in the paddock. The 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 both crops on all soils, and in many cases, resulted in higher N concentrations in

55 Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

56 R Pandey, B Singh, TVR Nair (2005) Impact of arbuscular-mycorrhizal fungi on phosphorus efficiency of wheat, rye, and triticale. Journal of Plant Nutrition, 28 (10), 1867–1876.

57 Summit Fertilizers (n.d.) Sulfur (S). Summit Fertilizers, http://www.summitfertz.com.au/research-and-agronomy/sulfur.html

58 GRDC (2014) Soil testing for crop nutrition, southern region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingS

the forage. Sulfur fertilisation also increased the *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. [59]

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. [60]

One study found that sulfur (20 kg/ha-1) applied to plots of triticale produced a greater number of days to anthesis (126). [61]

5.7.1 Symptoms of deficiency

What to look for in the paddock

- Areas of pale plants (Photo 8). [62]

What to look for in the plant

- Plants grow poorly and lack vigour, and have reduced tillering, delayed maturity and lower yields and protein levels.
- The youngest leaves are affected first and most severely.
- The leaves on deficient plants leaves turn pale with no stripes or green veins, but generally do not die although growth is retarded and maturity delayed (Photo 9).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red.
- Additional applied N can exacerbate the yellowing.

59 RL Feyh, RE Lamond, DA Whitney, RG Sears (1993) Sulfur fertilisation of wheat and triticale for forage production 1. Communications in Soil Science & Plant Analysis, 24 (5–6), 443–455.

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

61 B Iqbal, B Ahmad, I Ullah, AA Khan, S Anwar, A Ali, K Shahzad, S Khan (2016) Effect of phosphorus, sulfur and different irrigation levels on phenological traits of Triticale. Pure and Applied Biology, 5 (2), 303–310.sulfur

62 DAFWA (2015) Diagnosing sulfur deficiency in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-sulfur-deficiency-cereals

Photo 8: *Areas of pale plants characterise sulfur deficiency.*

Source: DAFWA

Photo 9: *Leaves showing some yellowing.*

Source: DAFWA

What else it could be

Before assuming sulfur deficiency, eliminate other possible causes of symptoms (Table 8).

Table 8: *Other possible problems of triticale that could be confused for sulfur deficiency.*

Condition	Similarities	Differences
Iron deficiency	Pale new growth	Iron-deficient plants have interveinal chlorosis
Group B herbicide damage	Seedlings with pale new leaves	Plants generally recover from Group B herbicide damage; and leaves often have interveinal chlorosis.
Waterlogging, or nitrogen, molybdenum or 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, and manganese, nitrogen and molybdenum deficiency

Source: DAFWA

5.7.2 Managing sulfur

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. [63]

Modern high-analysis fertilisers will usually contain enough S 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 after seeding as amsul (sulphate of ammonia).

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

Supplies of sulfur (elemental or sulphate)

Plants take up sulfur in the sulphate (SO4) form. The sulfate form is water-soluble, and being an anion, readily leaches. The elemental form of sulfur needs to be broken down into the sulfate form before becoming available to the plant. This is achieved by bacteria (*Thiobacillus* spp.) which digest the sulfur and excrete sulfate. All soils contain these bacteria. It takes about a fortnight for elemental sulfur to start breaking down, so it should be used before a plant deficiency can be seen. In waterlogged conditions, where sulfate will be lost by leaching or run-off, the bacteria will become dormant, so sulfur will not be lost.

Pros and cons of the two sulfur sources

Sulfate sulfur is:

- immediately available to the plant
- water-soluble
- quick acting
- leachable
- easily lost with one heavy rainfall

Elemental sulfur is:

- released slowly
- not lost by leaching

63 DAFWA (2015) Diagnosing sSulfur deficiency in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-sulfur-deficiency-cereals

- more available when maximum plant growth occurs in spring
- will build up a sulfur 'bank'
- slow to break down
- not suitable to correct a visible deficiency in plants [64]

5.8 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 sowing or within four 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. It 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, and helps to form and move starches, sugars and oils. Available potassium exists as an exchangeable cation associated with clay particles and humus. [65]

A study in Europe found that triticale is more sensitive to potassium deficiency than to phosphorus deficiency. [66]

Other research showed that the highest rate of grain yield for triticale (6.1 t/ha–1) was obtained by application of 160 kg/ha-1 of nitrogen and 90 kg/ha-1 of potassium. The application of different levels of nitrogen affected grain protein of triticale, but using different amounts of potassium did not. [67]

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. [68]

High potassium:sodium (Na) ratios in wheat and some triticale varieties can induce magnesium (Mg) deficiency in grazing stock, which may show up as tetany. 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 Mg content of cereal is typically satisfactory for stock, but the high K content and very low Na content of forage result in a high rumen K:Na ratio, which impedes magnesium absorption in the rumen.

Sheep and cattle grazing cereals can therefore have a sodium deficiency and a magnesium deficiency. [69]

MORE INFORMATION

Mineral supplements needed when grazing cereals

64 Summit Fertilisers (n.d.) Sulfur (S). Summit Fertilizers, http://www.summitfertz.com.au/research-and-agronomy/sulfur.html

65 Soilquality.org (n.d.) Potassium: NSW. Soilquality.org.au, http://www.soilquality.org.au/factsheets/potassium-nsw

66 R Gaj (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).

67 SA Tababtabaei, GH Ranjbar (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.

68 GRDC (2014) Soil testing for crop nutrition, southern region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingS

69 L Bell, H Dove (2012) Mineral supplements needed when grazing cereals. Ground Cover. No. 98, May–June 2012. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-98-May-June-2012/Mineral-supplements-needed-when-grazing-cereals

5.8.1 Symptoms of deficiency

What to look for in the paddock

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows (Photo 10). [70]
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease.

What to look for in the plant

- Plants appear paler, and weak and floppy (Photo 11).
- 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.

Photo 10: *There are fewer symptoms in header rows.*

Source: DAFWA

70 DAFWA (2015) Diagnosing potassium deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-wheat

Photo 11: *Potassium-deficient plants may display floppy older leaves and furled flag leaf from water stress.*

Source: DAFWA

What else it could be

Before assuming potassium deficiency, eliminate other possible causes of symptoms (Table 9).

Table 9: *Other possible problems of triticale that could be confused for potassium deficiency.*

Condition	Similarities	Differences
Molybdenum deficiency	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
Nitrogen deficiency	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
Spring drought	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
Root lesion nematodes	Smaller, water-stressed, pale plants	Root-lesion-nematode affected plants have 'spaghetti' roots with few feeder roots

Source: DAFWA

MORE INFORMATION

[Potassium responses observed in South Australian cereals]

Topdressing potassium will generally correct the deficiency. Foliar sprays generally cannot supply enough potassium to overcome a severe deficiency and can also scorch crops. [71]

5.8.2 Managing potassium

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 won't define a potassium requirement. These results are generally too late to be useful in the current season, but inform the need to assess K requirements for the next crop.

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 10).

Table 10: *Critical (Colwell) soil test thresholds for potassium (in ppm).*

	Deficient	Moderate	Sufficient
Cereals, canola, lupins, etc. (Brennan and 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.

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

Fertiliser types

Sulphate of potash (SOP), or potassium sulphate, is usually recommended if soils are deficient in K. Applying the cheaper muriate of potash (MOP), or 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 topdressed 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. [72]

71 DAFWA (2015) Diagnosing potassium deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-wheat

72 Soilquality.org (n.d.) Potassium: NSW. Soilquality.org.au

5.9 Micronutrients

Key points:

- Trace elements are important in particular situations but are not miracle workers.
- Deficiencies are not uncommon, but when they occur can result in large yield penalties.
- Diagnosis by soil tests and tissue tests 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 of the efficacy of products in their region.

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 tiny quantities, copper (Cu), manganese (Mn), iron (Fe), zinc (Zn), boron (B) and molybdenum (Mo) are all essential for plant growth. Essential trace elements are nutrients which are required by plants and animals to survive, grow, and reproduce, but are needed in only minute amounts. Southern Australian cropping soils are more likely to be deficient in zinc (Zn), copper (Cu), and manganese (Mn) than the other trace elements.

Of these three, Zn deficiency is probably the most important because it occurs over the widest area. Zn deficiency can severely limit annual pasture-legume production and reduce cereal-grain yields by up to 30%. Cu deficiency is also important because it may result in total crop failure.

If Zn, Cu and Mn are not managed well, the drop in productivity of crops and pastures can leave the farmer suffering expensive losses, and further production can also be lost through secondary effects such as increased disease damage and susceptibility to frost.

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

Many soils in the cropping zone of southern Australia are deficient in trace elements in their native condition. Despite many decades of research into trace-element management, crops can still be found to be deficient in one or more of these elements. It is important to keep an eye on trace-element levels as part of regular farm management: just because trace element deficiencies have not been prevalent in recent years, does not mean they will not return. There is increasing concern in some districts that trace-element deficiencies may be the next nutritional barrier to improving productivity. This is because current cropping systems are exporting more nutrients to the grain terminal than ever before. [73]

Triticale grows productively on alkaline soils where certain trace elements are deficient enough that they will not be suitable for other cereals. [74]

South Australia has a long and proud history of micronutrient research, and in the early 1960s it was found that foliar sprays of Mn onto barley gave a 20-fold response in the southern Yorke Peninsula. This was the first time foliar trace elements had been applied to agricultural crops in Australia. Similarly, with copper, South Australian scientists have led the way with diagnosis and remediation, as well as developing a deep understanding of cultivar differences in copper (and manganese) responses. Even so, between farms and within farms, the response to micronutrients will differ. [75]

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

74 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

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

MORE INFORMATION

[Detecting and managing trace element deficiencies in crops]

[Trace elements: copper and manganese—their role, requirements and options]

[Trace element disorders in South Australian agriculture]

In early trials, it has been reported that triticale has the Cu, Zn and Mn efficiency traits derived from its cereal rye parent. Triticale usually performs remarkably well on highly calcareous soils which are often deficient in Mn and Zn and sometimes in Cu. [76]

One study from Europe suggests that calcium, magnesium and potassium are the mineral nutrients most likely to limit triticale yield. [77]

5.9.1 Manganese

Many triticale cultivars carry tolerance to soils high in manganese, which is typical of some soils of Australia. [78]

Symptoms of deficiency

What to look for in the paddock

- Manganese deficiency often appears as patches of pale, floppy plants in an otherwise green, healthy crop (Photo 12). [79]

What to look for in the plant

- Plants are frequently stunted and occur in distinct patches.
- The middle leaves are affected first, but it can be difficult to determine which leaves are the most affected as symptoms rapidly spread to other leaves and the growing point (Photo 13).
- Leaves develop interveinal chlorosis and/or white necrotic flecks and blotches.
- Leaves often kink, collapse, and eventually die.
- Tillering is reduced, with extensive leaf and tiller death. With extended deficiency, the plant may die.
- Surviving plants produce fewer and smaller heads.

76 D Reuter (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

77 R Gaj (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).

78 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

79 DAFWA (2015) Diagnosing manganese deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-wheat

Photo 12: *Patches of pale, floppy plants in otherwise healthy crop.*

Source: DAFWA

Photo 13: *Middle leaves are affected first, and show yellowing and necrosis.*

Source: DAFWA

What else it could be

Before assuming potassium deficiency, eliminate other possible causes of symptoms (Table 11).

Table 11: *Other possible problems of triticale that could be confused for potassium deficiency.*

Condition	Similarities	Differences
Zinc deficiency	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.
Nitrogen deficiency	Pale plants	Nitrogen-deficient plants do not show wilting, interveinal chlorosis, leaf kinking and death
Waterlogging	Pale plants	Waterlogged plants do not show wilting, interveinal chlorosis, leaf kinking and death
Iron deficiency	Pale plants	New leaves are affected first. and plants do not die
Sulfur deficiency	Pale plants	New leaves are affected first. and plants do not die

Source: DAFWA

Managing manganese deficiency

- Use a 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. [80]

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 (3–5 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, and 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 to coat the 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 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. [81]

5.9.2 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. [82]

IN FOCUS

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

Researchers investigated the tolerance of triticale to low copper in a soil adjusted to extremes of pH, and compared it with the tolerance of its parent species, wheat and rye. The experiment was conducted using plants in pots of soil in a glasshouse. The 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. Triticale demonstrated intermediate tolerance by virtue of the copper–pH–genotype interaction: it was tolerant (like rye) at pH 5.0, but sensitive (like wheat) at pH 8.4.

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 symptoms of copper deficiency in all plants that had low yields suggests that the major effect of pH in this system was on copper availability; the change in availability was, however,

80 DAFWA (2015) Diagnosing manganese deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-wheat

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

82 RD Graham (1978) Tolerance of triticale, wheat and rye to copper deficiency. Letters. Nature, 271, 542–543.

insufficient to affect the response of wheat (which is highly sensitive) or of rye (highly tolerant). Triticale responded dramatically to the pH treatment and, as predicted, for such a hybrid was generally intermediate in tolerance to copper deficiency. [83]

Symptoms of deficiency

What to look for in the paddock

- Before head emergence, deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green, healthy crop (Photo 14). [84]
- 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 in recently limed paddocks.

What to look for in the plant

- The youngest growth is affected first.
- The 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 15).
- The base of the leaf can remain green.
- Old leaves remain green, but are paler than normal.
- Tiller production may increase, but tillers 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.

83 SP Harry, RD Graham (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.

84 DAFWA (2015) Diagnosing copper deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-wheat

Photo 14: *Pale, necrotic flag leaf at head emergence.*

Source: DAFWA

Photo 15: *Partly sterile head and twisted flag leaf.*

Source: DAFWA

What else it could be

Before assuming copper deficiency, eliminate other possible causes of symptoms (Table 12).

Table 12: *Other possible problems of triticale that could be confused for copper deficiency.*

Condition	Similarities	Differences
False black chaff	Discoloration on the upper stem and glumes	False black chaff does not affect yield or grain quality
Molybdenum deficiency	White heads and shrivelled grain	Molybdenum deficiency affects middle leaves first rather than the youngest leaf
Boron deficiency	Youngest leaf death	Boron-deficient plants are dark rather than light green, and affected leaves have marginal notches and split near the base
Stem and head frost damage	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)
Take-all	White heads and shrivelled grain	Take-all causes blackened roots and crowns and often kills the plant

Source: DAFWA

Managing copper deficiency

- Use 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, being available to the plant only 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 in deep increases the chances of roots being able to obtain enough copper when the topsoil is dry.
- Copper seed treatment is insufficient for the requirements of actively growing plants. [85]

Traditionally, Cu deficiency has been corrected by applying Cu-enriched fertilisers and incorporating them into the soil. Most soils require 2 kg Cu/ha to fully correct a deficiency, and this application may be effective for many years. Due to the excellent residual benefits of soil-applied Cu, deficiency of this element in crops and pastures has been largely overcome in most areas following the use of '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).

85 DAFWA (2015) Diagnosing copper deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-wheat

Application of Cu by Cu-enriched fertilisers are an important management strategy. Cu deficiency in crops can also be corrected by fluid application at seeding, which can be cheaper than Cu and Cu-enriched fertiliser treatments. 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 Cu/ha) is very cheap (approximately 90 c/ha for the ingredient) but a second spray immediately before 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 needed to completely eliminate Cu deficiency in an area that was extremely deficient in the trace element and the problem had been exacerbated by a dry spring when wheat was forming pollen and setting grains. [86]

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. Including 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. Copper is commonly applied in southern Victoria and on lighter soil types in western Victoria and parts of Gippsland whenever molybdenum is applied. Copper is not normally applied in northern Victoria. [87]

5.9.3 Zinc

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

Triticale is thought to have a high tolerance to Zn deficiency compared to wheat. The resistance index for Zn in triticale has been estimated at 75%, second only to rye, which is a very resistant crop to Zn deficiency. [88]

In one experiment, Zn deficiency symptoms were either absent or only slightly apparent 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% visible in triticale, 34% in bread wheats and 70% 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% for rye, 74% for triticale, 59% for bread wheats and 25% for durum wheats. [89]

Symptoms of deficiency

What to look for in the 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.

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

87 Agriculture Victoria (2008) Trace elements for dryland pastures. Note AG0265. Revised. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/trace-elements-for-dryland-pastures

88 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

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

What to look for in the 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 16). [90]
- Maturity is delayed. [91]

Photo 16: *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 it could be

Before assuming zinc deficiency, eliminate other possible causes of symptoms (Table 13).

90 DAFWA (2015) Diagnosing zinc deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

91 DAFWA (2015) Diagnosing zinc deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

Table 13: *Other possible problems of triticale that could be confused for zinc deficiency.*

Condition	Similarities	Differences
Manganese deficiency	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
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
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

Source: DAFWA

Managing zinc deficiency

- Use a 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, being available to the plant only when the topsoil is wet.
- Mixing zinc through the topsoil improves availability due to more uniform nutrient distribution.
- Zinc drilled in deep increases the chances of roots being able to obtain enough of the element when the topsoil is dry.
- Zinc seed treatment is used to promote early growth where root disease is a problem, but the level will be lower than a growing plant needs in a given season.
- Zinc present in compound fertilisers often meets the current requirements of the crop. [92]

Zinc may be required on light-textured soils such as sands or sandy loams, and particularly those that are alkaline, as the more alkaline the soil, the lower the availability of zinc for plant uptake. Most of the alkaline soils in Victoria occur in the Wimmera and Mallee, but there are a few pockets of alkaline soils in the higher-rainfall areas of the state. Plant responses to Zn on pasture are rare, but where required zinc should be applied at about 1–2 kg/ha, every 5–6 years. [93]

Correction of Zn deficiency in a way that provides benefits after the year of treatment is possible through the use of Zn-enriched fertilisers, or with a pre-sowing spray of Zn onto the soil, which will be incorporated with subsequent cultivation. 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).

Only Zn-enriched fertilisers of the homogenous type (i.e. fertiliser manufactured so that all granules contain some Zn) are effective at correcting Zn deficiency in the first year of application. A rate of 2 kg of elemental Zn per hectare applied to the soil is necessary to overcome a severe Zn deficiency; it should persist for three to 10 years,

92 DAFWA (2015) Diagnosing zinc deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

93 Agriculture Victoria (2008) Trace elements for dryland pastures. Note AG0265. Revised. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/trace-elements-for-dryland-pastures

depending on the 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 10 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. Few zinc-enriched fertilisers are now sold as homogeneous types, but providing a homogeneous fertiliser is used as part of the mix the final product is still satisfactory for correcting Zn deficiency. For example, the company may produce a diammonium phosphate (DAP) Zn 5% 'parent' product which has Zn on every granule which they will then blend with straight DAP to give 1% and 2.5% 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. Zinc can be mixed with many herbicides and pesticides, but not all, so check with your supplier for compatible tank mixes. Recent trials in eastern Australia suggest that chelated sources of trace elements are no more effective at correcting a deficiency than their sulphate forms.

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. [94]

5.9.4 Iron

Iron (Fe) 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, which are 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. [95]

Symptoms of deficiency

What to look for in the paddock

- Pale plants, particularly in waterlogged or limed areas (Photo 17). [96]

What to look for in the plant

- The youngest growth is affected first and most severely.
- Symptoms begin with young leaves turning pale green or yellow.
- Interveinal areas become yellow and in severely deficient plants interveinal areas turns almost white (Photo 18).
- 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.

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

95 RHJ Schlegel (2013) Rye: Genetics, Breeding, and Cultivation. CRC Press.

96 DAFWA (2015) Diagnosing zinc deficiency in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-cereals

Photo 17: *Pale green to yellow plants may be an indication of iron deficiency.*

Source: DAFWA

Photo 18: *Pale yellow, iron-deficient leaves, most showing prominent green veins (the three on the right) compared with dark green healthy leaf (left).*

Source: DAFWA

What else it could be

Before assuming iron deficiency, eliminate other possible causes of symptoms (Table 14).

Table 14: *Other possible problems of triticale that could be confused for iron deficiency.*

Condition	Similarities	Differences
Sulfur deficiency	Pale plants with pale new growth	Sulfur-deficient plants do not have interveinal chlorosis
Group B herbicide	Pale seedlings with interveinal chlorosis on new leaves	Herbicide-damaged plants generally recover, and are not restricted to waterlogged areas
Waterlogging, or nitrogen, molybdenum and manganese deficiency	Pale growth	Middle or older leaves are affected first

Source: DAFWA

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 as soil and air temperatures rise.
- Foliar sprays will remove the symptoms where they occur in highly calcareous or limed soils. [97]

5.10 Nutritional deficiencies

Many soils in the cropping zone of southern Australia are deficient in macronutrients and micronutrients in their native condition. To help identify nutritional deficiencies, see the GRDC's Winter Cereal Nutrition: the Ute Guide.

5.10.1 Making use of the crop-nutrition information available to you

As part of the GRDC's More Profit from Crop Nutrition (MPCN) extension and training project for the southern region, The Birchip Cropping Group (BCG), in conjunction with other grower groups, has been hosting nutrition events across the southern region since 2012. The most important nutritional areas are being investigated through the MPCN initiative; however, there are a few immediate resources available to advisers to help with understanding nutrition and giving such advice.

Useful resources

- More Profit from Crop Nutrition (MPCN)—extension and training for the southern region.
- The Extension Hub on crop nutrition—connects the lab and the paddock, and provides updates on the latest research, and articles focussing on strategic management of crop nutrition in the current season.
- Better Fertiliser Decisions for Cropping (BFDC)— provides the fertiliser industry, agency staff and agribusiness advisors with knowledge and resources to improve nutrient recommendations for optimising crop production.
- The page Making Better Fertiliser Decisions for Cropping Systems in Australia on BFDC provides the fertiliser industry, agency staff and agribusiness advisers with knowledge and resources to improve nutrient recommendations for optimising crop production.
- Nutrition technical workshops are being held by AgCommunicators as part of the GRDC's technical workshop projects. Multiple MPCN projects are presented at these workshops.

97 DAFWA (2015) Diagnosing iron deficiency in wheat. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-cereals

MORE INFORMATION

MPCN extension and training project

Better fertiliser decisions

Detecting and managing trace element deficiencies in crops

- Birchip Cropping Group—organises events and workshops, which are advertised on BCG's website, and often promoted in the area where an event will be held. This group expands the worth of its project by contributing data and results to crop-nutrition publications and to various other cropping publications in the region. [98]

98 A Elliott (2016) Making use of the crop nutrition information available to you. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Making-use-of-the-crop-nutrition-information-available-to-you