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GRDC GROWNOTES™

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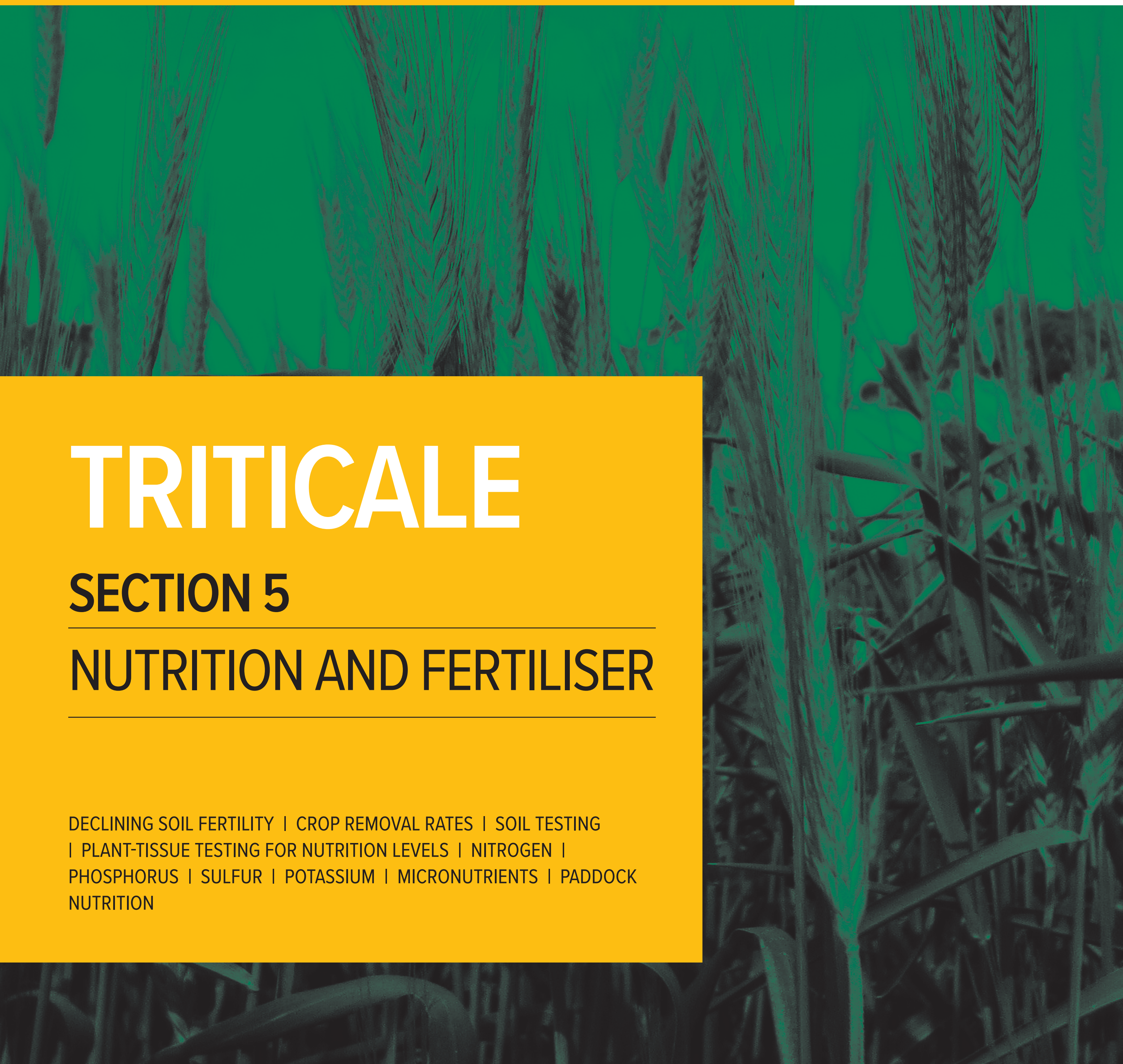


TRITICALE

SECTION 5

NUTRITION AND FERTILISER

DECLINING SOIL FERTILITY | CROP REMOVAL RATES | SOIL TESTING | PLANT-TISSUE TESTING FOR NUTRITION LEVELS | NITROGEN | PHOSPHORUS | SULFUR | POTASSIUM | MICRONUTRIENTS | PADDOCK NUTRITION

Nutrition and fertiliser

Key messages

- In nutrient-deficient soils, triticale appears to respond better to applied fertilisers than other cereals do: it can survive by utilising trace elements in soils which would be considered deficient for any other type of crop. However, the growth and yield of triticale are very responsive to phosphorus and nitrogen.
- Triticale has a higher nutrient-uptake efficiency than other crops.
- The nutrition requirements of triticale are similar to those of wheat. Triticale is very responsive to high inputs of seed and fertiliser. Adequate fertiliser is needed to achieve protein levels above 10%.
- Triticale grows productively on alkaline soils where certain trace elements are deficient for other cereals. It can also grow better than most other cereals on acidic soils.
- In the northern grain-growing region, soils are generally very fertile, although there is increasing evidence that fertility has been run down over time.
- Triticale is tolerant of acidic soils and those high in Aluminium.

High yields in any crop are strongly dependent on adequate nutrients being available during growth. Triticale has a very extensive root system (see 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 amounts of nitrogen and phosphorus inputs. [2]

1 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/docrep/009/y5553e/y5553e00.htm

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 of triticale plant, showing the extensive root system.*

Photo: Osborne Seed Company Variety Trials

This section covers several aspects of the availability of nutrients to plants: the fertility of soils, crop removal rates, tests to determine nutrient levels and imbalances, and fertilisation. To help identify nutritional deficiencies, also refer to the GRDC's Winter Cereal Nutrition: the Ute Guide, which has been made available as an app for mobile devices.

5.1.1 Declining soil fertility

In some areas of the Northern region, the natural fertility of cropped agricultural soils is declining over time. [3] This decline has not been seen in the central NSW region where N and P fertility is increasing. Grain growers must continually review their soil-management programs to ensure the long-term sustainability of high-quality grain production. Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils.

Paddock records that include yield and protein levels, results of fertiliser test strips, crop monitoring information, and the results of soil and plant tissue tests all help the grower to formulate an efficient and effective cropping program. 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 J Carson (2017) Biological inputs, northern grain-growing region. Soilquality.org, http://www.soilquality.org.au/factsheets/biological-inputs-northern-grain-growing-region

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 or even conducting tissue tests 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 for triticale should be based on soil testing and other historical response information, as well as anticipated costs and returns. It is therefore 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 to wheat and responds well to most compound fertilisers. Zinc has also been found to be a valuable added nutrient for many soils found in the Northern region. [7]

In trials in Armidale, Gerogery and Narrabri, 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 this experiment was conducted in 2004 and used varieties that have now been largely superseded, the major findings remain relevant: that, in a high-rainfall region with yield potential 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.

4 DAF Qld (2010) Overview [of nutrition management]. DAF Queensland, https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

5 DAF Qld (2010) Overview [of nutrition management]. DAF Queensland, https://www.daf.qld.gov.au/business-priorities/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

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

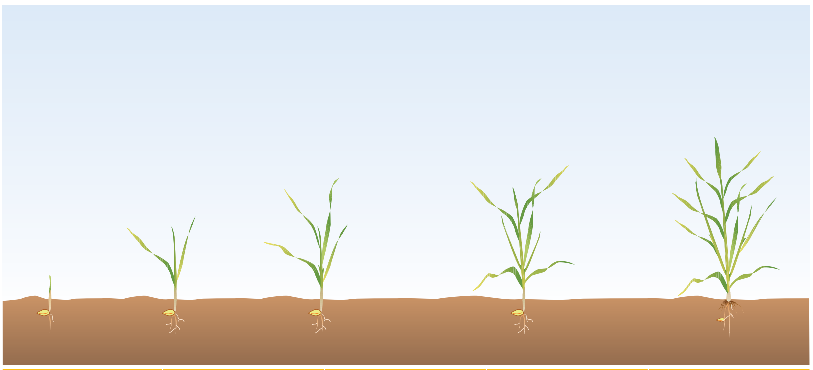
Variety	0 nitrogen	50 kg/ha nitrogen	100 kg/ha nitrogen	Response 100 kg/ha nitrogen
Everest	6.85	7.96	7.98	1.13
Kosciusko	7.37	7.48	8.34	0.97
Tahara	7.96	8.22	8.52	0.56
Janz wheat	6.73	6.99	7.00	0.27

Source: Jessop and Fittler 2009

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. [8]

A productive triticale will require 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 monoammonium phosphate (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 (when grazing triticale) 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, Figure 1).



Zadoks Growth Stage	GS 00-09	GS10-19	GS20-29	GS30-39	GS40-49
Development phase	Germination	Seedling growth	Tillering	Stem elongation	Booting

Figure 1: *The Zadoks cereal-growth stages.*

Source: GRDC

8 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

MORE INFORMATION

Crop nutrition: region by region

GRDC factsheet, Targeted nutrition at sowing

VIDEOS

WATCH: Over the Fence North: Gas and liquid fertiliser drives yield gains at Tulloona

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. [9]

Table 2 [10] 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
- 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

MAP = monoammonium phosphate, DAP = diammonium phosphate

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} (comprising 200 kg N + 40 kg P). The response of further increases in N + P rates gradually diminished thereafter, despite increasing N and/or P in the fertiliser combinations. [11]

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. Triticale has a low dependence on VAM (see table 3, below).

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, hence, plant growth. A plant's root system, however big, can never be as extensive as the network of fungal fibres.

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.

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

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

11 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.

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 is a phosphorus or zinc deficiency of the plant; it 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. [12]

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 is suggested that these differences are due to several factors, such as the use of fertilisers and agro-chemicals, and the influence of crop rotation. [13]

Management to optimise mycorrhizae

There are two important and distinct concepts to understand when considering the management of crops for optimising mycorrhizal levels. These are a crops' dependency on mycorrhizae (important for the growth of that particular crop) (Table 3) and that crops' ability to produce mycorrhizal inoculum (important for the growth of the following crop). A crop with a low dependency may still produce suitable levels of inoculum for the next crop.

AM dependency, the extent to which a crop relies on AM to achieve maximum growth, varies with the crop species and variety, and with the P and Zn status of the soil.

Table 3: *Mycorrhizal dependency rankings of summer and winter crops.*

Mycorrhizal dependency	Winter Crops	Summer Crops
Very High	Linseed Fababean	Cotton Maize Pigeonpea Lablab
High		Sunflower Soybean Navybean Mungbean Sorghum
Low	Fieldpea Oats Wheat Triticale	
Very Low	Barley	
Independent	Canola Lupins	

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

13 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.

If you suspect low numbers of AMF in your paddock:

- Grow crops with low or very low mycorrhizal dependency, e.g. triticale, 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. [14]

5.2 Crop removal rates

Each tonne of triticale harvested will remove approximately 23 kg N/ha from the paddock (Table 4). [15] So, if targeting 3 t/ha of grain then a minimum of 69 kg N/ha should be applied just to cover grain removal. If grazing is also included or soil nitrogen levels are low, additional N should be applied.

Table 4: *Nutrients removed (kg) per tonne of grain produced.*

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.
- 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.
- Fertiliser decisions are based in part on where the result of the soil test falls along the critical range.
- Critical ranges for combinations of nutrient, crop and soil types are still being established.
- Critical ranges are being established for topsoils (0–10 cm) and subsoils (10–30 cm in some cases, and to the depth of the crop root-zone in others), depending on the nutrient.
- Deeper sampling is considered to be essential for understanding soil nutritional status and fertiliser requirements in northern cropping systems.
- 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.

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

15 Agriculture Victoria (2008) Establishing forage cereals. Note AG1269. Revised. Agriculture Victoria

MORE INFORMATION

Deep P applications trialled in Central West NSW

Soil nutrient testing: how to get meaningful results

- Use local data and support services to help integrate soil test data into making profitable fertiliser decisions.

Recent research has highlighted that nitrogen applications can be wasted, even on cropping soils that have low N availability, if the levels of other nutrients such as potassium (K), P and sulfur (S) are not adequate.

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. 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.

There has recently been a lot of research conducted on the importance of subsoil layers for nutrients such as P and K in the Northern region.

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.
- Monitor soil fertility levels.
- Estimate which nutrients are likely to limit yield.
- Measure 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.
- Measure the occurrence of soil-borne diseases.
- Zone paddocks for variable application rates.
- Diagnose the reasons for poor plant performance—soil-test results are part of the information that support decisions about fertiliser rate, timing and placement.
- To quantify and physical problems e.g. compaction. [16]

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 to:

1. Use a representative sample of soil.
2. Analyse the soil using the accepted procedures that have been calibrated against fertiliser experiments in that region.
3. 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. [17]

16 GRDC (2014) Soil testing for crop nutrition (Southern Region). Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingS

17 D Loch (n.d.) Soil nutrient testing: how to get meaningful results. DAF Queensland, https://www.daf.qld.gov.au/__data/assets/pdf_file/0006/65985/Soil-Nutrient-Testing.pdf

MORE INFORMATION

Soil testing for crop nutrition (Northern Region)

VIDEOS

WATCH: Over the Fence North: Weed and nutrient research delivers at Silverton

5.3.3 Types of test

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

- bicarbonate extractable P (Colwell-P), ;
- acid extractable P (BSES-P), to assess slower release soil P reserves and the build-up of fertiliser residues (not required annually);
- bicarbonate extractable K (Colwell-K);
- KCl-40 extractable S; and
- 2M KCl extractable inorganic N, which provides measurement of nitrate-N and ammonium-N.

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), electrical conductivity (EC), and chloride and exchangeable cations (CEC) including aluminium. [18]

5.4 Plant-tissue testing for nutrition levels

Plant-tissue testing can be limited in its usefulness in monitoring crop health, because by the time noticeable symptoms appear in a crop the yield potential can be markedly reduced. Plant-tissue testing can also be used to diagnose a deficiency or monitor the general health of the crop.

To determine micronutrient status, plant tissue testing is usually more reliable than soil testing. [19]

The only way to know whether a crop is adequately nourished before visual symptoms indicate imbalances is to have plant tissue analysed during the growing season.

5.4.1 What plant-tissue analysis shows

Plant-tissue analysis shows the nutrient status of plants at the time of sampling. This, in turn, shows whether soil nutrient supplies are adequate. In addition, plant-tissue analysis will detect unseen deficiencies and may confirm visual symptoms of deficiencies. Toxic levels of nutrients may also be detected.

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.

18 GRDC (2014) Soil testing for crop nutrition, Northern region. Factsheet. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

19 GRDC (2014) Soil testing for crop nutrition. Northern Region. Factsheet. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

- 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.
- 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. [20]

The successful use of plant tissue analysis depends on sampling the correct plant part at the appropriate growth stage (Table 5).

Table 5: *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 21–31)	Youngest expanded blade (YEB) plus next 2 lower blades	25
Flag leaf ligule just visible to boots swollen (GS 39–45)	Youngest expanded blade (YEB) plus next 2 lower blades	25

Source: Back Paddock Company

5.5 Nitrogen

Key points:

- Nitrogen (N) is needed for crop growth in larger quantities than any other nutrient.
- Nitrate (NO_3^-) 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. [21]

The two forms of soil mineral N absorbed by most plants are nitrate (NO_3N) and ammonium (NHþ$_4$N) (see Figure 2). [22] In well-aerated soils during the growing season NO_3N becomes the main form of N available for crops as microbial activity quickly transforms NHþ$_4$N into NO_3N. It is crucial to keep NO_3N 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 NO_3N vary across space and over time. Proper agricultural management needs to consider both site-specific variations as well as temporal patterns in soil NO_3N to supply optimum amounts from both organic and mineral sources. [23]

20 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

21 GRDC (2006) Triticale. Ground Cover. Issue 59, 1 January 2006. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-59/Triticale

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

23 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), DOI 10.1371/journal.pone.0143358

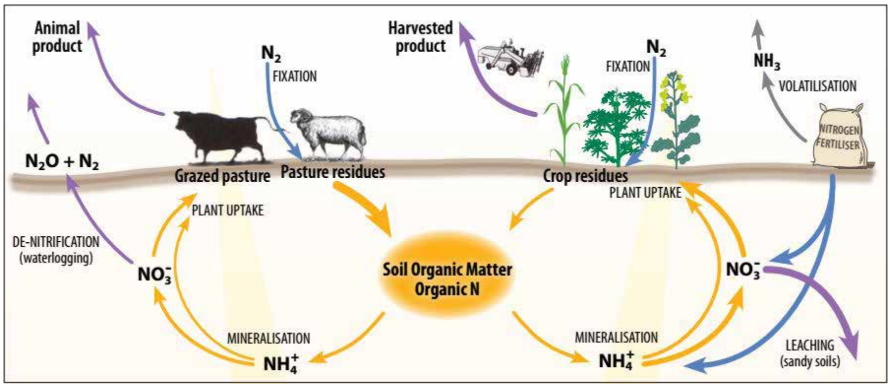

Figure 2: *How the two forms of soil mineral nitrogen fit into the principle nitrogen cycling pathways in mixed cropping–pasture systems.*

Source: Soilquality.org

The results of trials outside Canberra to explore crop management of dual-purpose cereals indicated that N should be applied at sowing to ensure good early plant growth and to build up Dry Matter production. 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 of nitrogen (in the form of urea) per hectare immediately after grazing finishes to boost plant recovery, if N budgeting indicates the crop may require this treatment. [24]

For more information on N budgeting, see Section 5.5.2 Managing nitrogen–N Budgeting, below.

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. Note that starting levels of nitrogen in the trials were not reported.

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 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. Triticale consistently out-

24 D Lush (2014) Rules of thumb for grazing cereals. Ground Cover. Issue 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

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, combined with good yield. [25]

IN FOCUS

Nitrogen timing for boot-stage triticale forage yield and phosphorus uptake

The optimal time to apply N for boot-stage winter triticale forage production and P removal is not well established. In a US experiment that took place in 2006 and 2007, irrigated winter triticale was grown on soils that were either low and relatively high in P (having been tested using the Olsen P test). The triticale was treated with six rates of autumn pre-plant N and two rates of late-winter N. The researchers measured triticale boot-stage biomass, protein, nitrate-N, P concentrations, and P uptake. The N applied in autumn increased forage production and frequently produced more boot-stage triticale biomass. It also tended to increase P uptake, but reduced P and forage-protein concentrations, probably due to plant dilution. In the high-P soil, higher N increased forage P concentrations in one of the two years. Forage protein in the range of 10.5–11.0% was needed to maximise forage production. [26]

MORE INFORMATION

Nitrogen decision–Guidelines and rules of thumb

Nitrogen monitoring tools

Lodging risk

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. However, breeding efforts have created varieties with a lower risk of lodging. The likelihood of lodging is increased by high rates of nitrogen fertiliser and under irrigated conditions. [27]

For example, in a field experiment at Mintaro, South Australia, researchers found that 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. [28]

For more information on how to manage a lodged crop, see Section 12.2.1–Lodging.

5.5.1 Symptoms of Nitrogen deficiency

Nutrient deficiency symptoms in triticale are similar to those in wheat and other cereals.

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

26 B Brown (2009) Nitrogen timing for boot stage triticale forage yield and phosphorus uptake. Western Nutrient Management Conference, http://www.extension.uidaho.edu/nutrient/pdf/smallgrain/New/Nitrogen timing for boot stage triticale forage yield and phosphorus uptake.pdf

27 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

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

What to look for in the paddock

Light green to yellow plants particularly on sandy soils or unburnt header or swathe rows (Photo 2). [29]

- Double-sown areas have less symptoms if nitrogen fertiliser was applied at seeding.
- Nitrogen deficiency can occur in waterlogged areas of the paddock.

What to look for in the plant

- Plants are pale green with reduced bulk, shorter stature 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 3).
- 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.

Photo 2: *Nitrogen deficiency on unburnt header row.*

Source: DAFWA

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

Photo 3: *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 6).

Table 6: *Other 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

5.5.2 Managing nitrogen

Key points:

- The first step to managing N is having a N budget for each paddock for each year.

VIDEOS

WATCH: GCTV14: Nitrogen deficiency

- Nitrogen is very mobile in the soil, it can move half the wetting front following a watering/rainfall event. This is both a benefit and in some cases a disadvantage.
- The amount of N that can be applied with the seed is limited.
- 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. [30]
- Trials in NSW found that triticale requires 80 kg/ha to maximise yield. [31]

Deficiency symptoms can be treated with N fertiliser or foliar spray or with urea etc. spread in front of rainfall or an irrigation event. 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. [32]

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.

N Budgeting

Matching plant demand with fertiliser N supply is important for a number of environmental and economic reasons. Nitrogen is lost through volatilisation, leaching and denitrification. By ensuring that the plant N use matches the fertiliser N you are minimising the chances of excess N reducing water quality and contributing to acidification.

More efficient use of nitrogen fertiliser reduces both greenhouse gas emissions and on-farm costs. Nitrous oxide, which can be emitted from N fertiliser applied to agricultural soils, is a potent greenhouse gas, having a global warming potential 310 times that of carbon dioxide. Using monitoring tools such as N budgeting will ensure that fertiliser applied to pasture and crops will provide maximum production benefit with minimal environmental impact.

Steps

- Step 1: Record paddock name
- Step 2: Calculate target yield: One good way to calculate a target yield is to use the French-Schultz approach:

Where growing season rainfall is the total received between April–October:

Triticale potential yield = 18 x (growing season rainfall in mm–90)

Wheat potential yield = 20 x (growing season rainfall in mm–110)

Barley potential yield = 18 x (growing season rainfall in mm–90)

Oats potential yield = 22 x (growing season rainfall in mm–90)

Grain legumes potential yield = 12 x (growing season rainfall in mm–130)

- Step 3: Calculate N budget: Using Table 7 (and Table 8 to correct for the extra N that becomes available over the growing season).
- Step 4: Apply correct amount of fertiliser: Urea contains 46% N, ammonium nitrate 34% N, di-ammonium phosphate (DAP) 18% N, mono-ammonium phosphate (MAP) 11.3% N, and sulphate of ammonia 21% N. But note that sulphate

30 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

31 J Sykes (2005) Triticale maximum yield experiment. Riverine Plains. Online Farm Trials. http://www.farmtrials.com.au/trial/16484?search_num=3

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

of ammonia is highly acidifying and needs between 4–7 kg lime per kg N applied to balance the acidity; see Acidity Tools for further details.

Table 7: *Nitrogen budget based on an autumn-winter deep soil N test to 60 cm depth*

		Example	Growers' calculation
Crop demand			
	Target yield	4.0 t/ha	
Multiplied by	Target protein	X 13%	
Multiplied by	Correction factor	X 2.34	
Equals	N-demand	122 kg N/ha	
Soil supply			
	Measured soil mineral N in the top 60 cm at sowing–autumn - winter deep-soil-N test.	100 kg N/ha	
Add	Estimated production of mineral N (mineralisation*) during crop production–see Table 8.	80 kg N/ha if low fertility soil	
Equals	Gross N supply	180 kg N/ha	
Less	Assume 50% is not taken up by the crop**	- 90 kg N/ha	
	Net N-supply	90 kg N/ha	
Fertiliser needed			
Subtract soil supply from crop demand	Net extra N required	122 - 90 = 32 kg N/ha	
Crop demand: multiply "Net extra N required" by 2	Fertiliser N needed (assuming 50% efficiency of N recovery)***	32 x 2 = 64 kg N/ha	

Mineralisation of N (marked as * in Table 7, above), that is N made available to plants by the breakdown of plant residues and organic matter, is fastest in warm, moist conditions. Most rapid mineralisation occurs after summer and autumn storms and is slowest in dry summers and also in mid-winter. Mineralisation continues during crop growth but is difficult to measure because the N is taken up by roots as fast as it is formed. It occurs at rates of up to 1 kg N/ha/day in moist, warm (≈16°C) topsoil in spring, and at about 0.2 kg N/ha/day in cold, wet soils in winter. Mineralisation rates in soils with retained stubbles can be 1–1.5 kg N/ha/day following rain while the soil remains wet, dropping to zero once the soil has dried out.

The 50% efficiency of N recovery by plants (marked as *** in Table 7, above) is based on many studies which show that plant tops on average take up at least half of the applied N. This does not necessarily mean that the remaining 50% is all lost. Roots can take up about 30% of the N, and thus some of this residual N will eventually become available to the next generation of plants once the roots decay. True losses of N occur from:

- Volatilisation (gaseous losses of N) can be high in warm conditions, particularly from top-dressed urea with no follow-up rainfall to wash in the urea granules, and on alkaline soils).
- Denitrification (commonly less than 5–10 kg N/ha) is only likely if soils are warm and waterlogged and have a high amount of nitrate present and a source of

carbon for microbes. Denitrification is the conversion of nitrate-N to gaseous N, and so is a loss of N which would have been available to plants.

- Leaching (loss of N in water–below the root-zone or laterally) as nitrate-N in wet years.

The amount of N fixed in different environments is determined by legume content and herbage yield. As a rule-of-thumb, 20–25 kg N in plant tops can be expected to be fixed on average for every tonne of legume dry matter produced. Assuming legume dry matter is not measured, Table 8 can be used to estimate N availability during the growing season.

Table 8: *Estimated within-growing-season mineralisation rates in southern NSW cropping soils (based on estimates of Mark Peoples, CSIRO Canberra).*

Fertility status of soil	Nitrogen (kg N/ha) which becomes available during the growing season
Low e.g. continuously cropped, low use of N fertilisers, N deficiency common in crops, < 0.08% topsoil total N.	60
Medium e.g. crop-pasture rotation, 2nd or 3rd crop into the rotation, moderate use of N fertilisers, 0.08–0.12% topsoil total N.	80
Moderate-high e.g. 1st crop after pasture, moderate clover pasture contained at least 20–30% clover, moderate use of N fertiliser, > 0.12% topsoil total N.	100
High fertility e.g.1st or 2nd crop after winter-cleaned pasture of high legume content (>50% legume content), > 0.12% topsoil total N.	160

Source: Agriculture Victoria).

The N benefits from subterranean clover or annual medic pastures rarely last beyond two years. Nitrogen benefits from lucerne can occur 2–3 years after lucerne removal (due to slower breakdown of lucerne residues than for annual legumes). However, if lucerne is removed only shortly before cropping, N fertiliser may be required for the first crop because it can take several weeks for the N in legume residues to break down and become available to other plants. N deficiency is unlikely to be a problem for spring-removed lucerne. [33]

For example, triticale used for grazing and grain could use up to 100 kg N/ha. Consider applying 60–100 kg N/ha as a topdressing if soil nitrogen levels are low, however this depends on N in the paddock, N removed, Dry Matter production and other variables. This is where working out an N budget is important. Long fallow paddocks following good legume pastures generally have satisfactory nitrogen levels. The contribution of 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. [34]

Timing of application

The two main questions with N management are how much N is needed, and when it should be applied.

Grain-yield improvements are mainly caused by increased tiller numbers and grains per head, both of which are determined early in the life of a triticale plant. A sufficient supply of nitrogen during crop emergence and establishment is critical. Nitrogen-use

33 Agriculture Victoria (2017) Nitrogen monitoring tools. http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/nitrogen-n

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

efficiency can be improved by delaying fertiliser application until the crop's roots system is adequately developed, 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 achieved. An advantage of late applications (once the first node is visible) is that growers have a better idea of seasonal conditions and what the yield potential might be before applying the nitrogen. [35]

The critical factor in budgeting the amount of N to apply is the target crop yield and protein yield, as crop yield potential is the major driver of N requirement. As a guide, Table 9 shows the N required for different yield and protein combinations at maturity and anthesis. [36]

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. [37]

Table 9: *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

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.

Source: GRDC

Optimising nitrogen-use efficiency

The three main stores in the soil of nitrogen that can feed crops is nitrogen in soil organic matter, nitrogen in plant residues, and mineral 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 is soil testing.

The release of nitrogen during the decomposition of organic matter in the soil is a significant supply of N to crops during the growing season. Most N models

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

36 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

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

estimate the amount of organic nitrogen in the soil from the amount of total organic carbon present.

Mineralisation is the main process by which soil organic matter is converted by microorganisms into plant-available forms of N (Figure 3). The amount of N mineralisation depends on three factors–the soil's total N content, its temperature and water content.

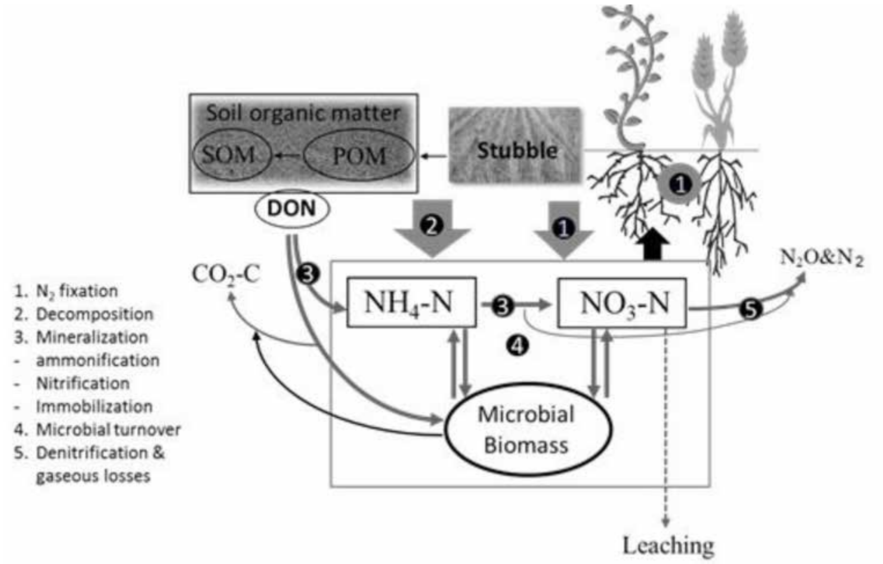

Figure 3: *Biological processes involved in nitrogen cycling that influence plant available nitrogen levels in soil. SOM–soil organic matter, DON–dissolved organic nitrogen, POM–particulate organic matter.*

Source: GRDC.

During the growing season, the amount of mineralisation is reasonably predictable and models are available that will estimate mineralisation over time periods ranging from days to years.

In the year after a legume crop or legume-based pasture, there is an additional burst of mineralisation from legume residues. In the first year after a legume, this can be one quarter of the legume's biologically-fixed N.

A rule of thumb for mineralisation, based on measurements in southern NSW in a continuously-cropped chromosol, is where there is 0.1% N in the top 10 cm, it mineralises about 0.3 kg N/ha/mm of summer rain and 0.5 kg N/ha/mm of summer rain after a legume.

Growers can include an estimate of in-crop mineralisation in a nitrogen budget when calculating fertiliser requirement for the 2015 growing season.

The amount of N mineralised between harvest and sowing of the next crop can be measured by soil sampling before sowing. But after sowing, the amount of N mineralised is more difficult to measure because there is simultaneous mineralisation of nitrogen in the soil and uptake by the growing crop. Models provide the best estimates of in-crop mineralisation. [38]

To work out the amount of N mineralisation over summer, estimate:

Organic carbon (OC%) x summer rainfall 0.15 = kg/N mineralised

The decomposition of plant residues, particularly those of legumes, can supply significant amounts of N to cereal crops. Generally the amount of N fixed by legume crops is proportional to the amount of vegetative growth and the amount of grain

38 A Lawson (2015) Understanding the factors that affect mineralisation. GRDC. https://grdc.com.au/Media-Centre/Media-News/South/2015/01/Understand-the-factors-that-affect-mineralisation

MORE INFORMATION

[Yield Prophet®]

[Factors influencing nitrogen supply from soils and stubbles]

removed (i.e. the harvest index). In loam or clay soils, legumes in rotation will have slightly higher levels of available nitrogen than sandy soils due to less leaching.

To accurately estimating how much nitrogen (and other nutrients) cereal crops require the grower needs an effective method of estimating yield potential: the basic assumption is that for every tonne of grain produced, a cereal crop requires 45 kg N. [39]

For more information on estimating yield potential, see Section 1: Planning and Paddock Preparation.

5.6 Phosphorus

Key points:

- Phosphorus is one of the most critical and limiting nutrients in agriculture in the Northern Region.
- Phosphorous cycling in soils is complex.
- Only 5–30% of phosphorus applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus fertiliser is best applied at seeding.
- Compared with bread wheats, triticale and rye have been found to be more efficient in using P at low levels of P supply. However, phosphorus fertiliser for triticale is recommended in the same amounts as those recommended for wheat, 10–15 kg/ha at sowing.
- Triticale has been classified as phosphorus-efficient; i.e., it is higher yielding than other cultivars under low P supply. Triticale has also been classified as phosphorus-responsive; i.e. it is higher yielding than other cultivars under high P supply. [40]

After nitrogen stress, phosphorus is the second most widely occurring nutrient deficiency in cereal systems around the world. [41] 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 4). [42] A soil's ability to fix phosphorus must be measured when determining requirements for crops and pastures. [43]

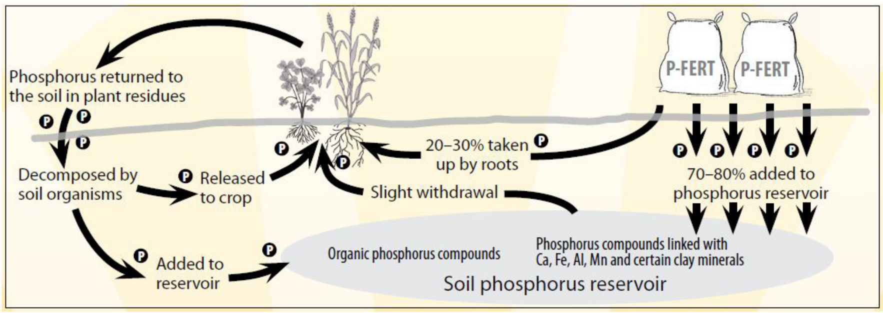

Figure 4: *The phosphorus cycle in a typical cropping system is particularly complex, because movement through the soil is minimal and availability to crops is severely limited.*

Source: Soilquality.org

39 Soilquality.org (2017) Optimising soil nutrition, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland

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 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.

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

43 R Quinlan, A Wherrett, S Alt (2017) Phosphorus, NSW. Factsheet. Soilquality.org.au, http://www.soilquality.org.au/factsheets/phosphorus-nsw

IN FOCUS

Cereal types, soil types and phosphorus use

Crop growth on the flats is typically thicker than on sand hills, but in most years grain yields are less. 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, and GRDC funded a project to investigate this.

It was already known that soil P levels in the topsoil (0–10 cm) do not vary markedly across different soil types in the Mallee: 19 ppm for soil in the flats, 17 ppm on the slopes and 11 ppm in the sand hills. In 2005 and 2006, the researchers applied different P treatments to crops on these soils. As well, in 2005, they 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 (the sand hills) than in the heavier soil zone (the 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 more than on the heavier shallow soil. This is consistent with lower levels of 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 the 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.

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). [44]

While there has been substantial improvement (e.g. through genetic gains) in terms of P responsiveness in triticale since its breeding in Australia, there has been little improvement in terms of phosphorus-use efficiency; i.e. performance in low-phosphorus conditions.

Triticale responds well to P application. A field experiment in Brazil found that triticale presented higher dry matter production and grain yield response to P than seven wheat cultivars did. [45]

Triticale also responds well to phosphorus application under drought conditions. [46]

The presence of other elements influences the availability of P. For instance, phosphorus deficiency is thought to be responsible for biomass reduction of triticale in nutrient solution with aluminium, an issue on acidic soils. One study suggests that

44 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, https://grdc.com.au/research/reports/report?id=986

45 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.

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/docrep/009/y5553e/y5553e00.htm

in previous experiments, P deficiency was probably the most important limiting factor in acid nutrient solutions with aluminium. [47]

In sandy soils P has a tendency to leach out of the soil. Soils with sufficient levels of 'reactive' iron (Fe) and aluminium (Al) will tend to resist phosphorus leaching. If growers have sandy soils with low 'reactive' levels of Fe and Al then they should test P levels and apply less phosphorus more often, so that phosphorus isn't lost 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. [48]

5.6.1 Symptoms of Phosphorus 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 4). [49]
- Affected areas are more susceptible to leaf diseases.
- Lines in the crop where there is a missed strip of fertiliser.

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 5 and 6).
- 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.
- Plant maturity is delayed.

Photo 4: *Stunted early growth with reduced tillers in P deficient crop on the left.*

Source: DAFWA

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

48 G Bailey, T Brooksby (2016) Phosphorus in the south east soils. Download on web page South East soil issues, Natural Resources South East, http://www.naturalresources.sa.gov.au/southeast/land/soil-management/South-East-Soil-Issues

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

Photo 5: *P-deficient plants on the left are later maturing with fewer and smaller heads.*

Source: DAFWA

Photo 6: *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

The symptoms above may also be due to other causes (Table 10).

Table 10: *Other 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 phosphorus buffer index (PBI, a measure of phosphorus retention), particularly on coastal plains. Topdressing is effective on these soils. [50]

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. [51]

5.6.2 Managing phosphorus

Key points:

- P reserves can be run down over several decades of cropping. However, after decades of consistent P application, many soils in Australia 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.

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

51 G Bailey, T Brooksby (2016) Phosphorus in the south east soils. Download on web page South East soil issues, Natural Resources South East, http://www.naturalresources.sa.gov.au/southeast/land/soil-management/South-East-Soil-Issues

VIDEOS

WATCH: [GCTV13: Phosphorus uptake]

WATCH: [Improving phosphate use efficiency]

WATCH: [Over the Fence North: Deep P placement delivers yield return on Darling Downs]

MORE INFORMATION

[Crop nutrition: Phosphorus management—Northern Region]

- 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 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. [52]

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. [53]

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

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

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. [54]

5.7 Sulfur

Sulfur is an essential plant nutrient that (along with N) is required for the production of amino acids, which 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 sulfur, 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. Sulfur remaining in plant residues is readily recycled into the soil. [55]

Historically, adequate S has been supplied by mineralisation from organic matter, from being applied as a nutrient in N and P fertilisers (sulfate of ammonia and superphosphate), or via the presence of calcium sulfate layers in the subsoil that are accessible to the roots. However, with the increased use of high-analysis N and P fertilisers that are low in S, deficiency in crops is increasing, especially in wet years, due to leaching. S deficiency appears to occur because of a complex interaction between seasonal conditions, crop species and plant availability of subsoil S, which

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

53 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

54 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.

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

impact on the ability of the soil S test to predict plant-available S. Deficiencies may be more evident in wet years due to S leaching. [56]

Triticale and sulfur

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.

Early 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 (note that starter S levels were not stated). Sulfur fertilisation increased forage yields and S concentrations of both crops on all soils, and in many cases, resulted in higher N concentrations in 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. [57]

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

It should be noted that these trials are based primarily on greenhouse trials, and not in the paddock.

> *Whilst greenhouse data is helpful, paddock trials are important, and unfortunately these are limited in triticale. Growers should be aware of S levels and budget accordingly, but in my experience, there is often no dry matter increases in cereals due to S application in central-western NSW over many years of S use.*

Agronomist's view

5.7.1 Symptoms of Sulfur deficiency

What to look for in the paddock

- Areas of pale plants (Photo 7). [59]
- Areas of acidic soils.
- Soils low in organic matter.

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 8).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red usually on the northern, sunny side.

56 GRDC (2014) Soil testing crop nutrition, Northern Region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingN

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

58 B Lasztity (1993) The variation of sulfur contents and uptakes in triticale during growth. Agrochimica.

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

Photo 7: *Areas of pale plants characterise sulfur deficiency.*

Source: DAFWA

Photo 8: *Leaves on sulfur deficient cereal plants become uniformly pale.*

Source: DAFWA

What else it could be

The symptoms described above may also my caused by other issues (Table 11).

Table 11: *Other problems of triticale that could be confused for sulfur deficiency.*
Source: DAFWA

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

5.7.2 *Managing sulfur*

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

Foliar sprays generally cannot supply enough sulfur for plant needs. [60]

Modern high-analysis fertilisers will usually contain enough S to supply sufficient levels to cereal crops.

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 sulfur 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 fall of rain

Elemental sulfur is:

- released slowly
- not lost by leaching
- more available when maximum plant growth occurs in spring

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

- will build up a sulfur 'bank'
- slow to break down. [61]

Local tools help S fertiliser decision making

There are few summaries of information specifically about S nutrition for cereals grown in eastern Australia. This reflects historic rarity of S deficiency in cereals grown in the region as well as grain price being unrelated to S content in the grain. Fact sheets (based on information from Western Australia) highlight the need to consider the soil type as it relates to S adsorption capacity and potential for S leaching. Soils with clay, or iron and aluminium oxides retain S through adsorption and tend to be less prone to S leaching. Conversely, deep sandy soils, particularly subject to high rainfall conditions, are prone to S leaching. Under these conditions or when soil testing, plant testing or historical records show there is a risk of cereal becoming S deficient it is useful to know the amount of S removed by the crop.

The amount of S in wheat in south-eastern Australia is 1.5 kg S/ t stubble and 1.7 kg S/t grain. In New South Wales, the amount of S removed by dual purpose wheat (i.e. grazed and harvested for grain) is given as 0.4 kg S/t dry matter grazed and 1.5 kg S/t grain (these figures can be used as a guide for triticale). Calculations for the amount of S fertiliser needed in any crop is based on supplying the crop with enough S to cover immediate nutrient usage or removal. The amount of S required is given as 20 kg S/ha to meet the needs of dual purpose wheat in New South Wales (these figures can be used as a guide for triticale). However, S recommendations tend not to be based on preventing nutrient removal, rather S tends to be recommended when deficiencies are expected. [62]

MORE INFORMATION

Sulfur as a nutrient for agricultural crops in southern and eastern Australia

Sulfur in Northern Vertosols

5.8 Potassium

Key points:

- Soil testing combined with plant-tissue testing is the most effective means of determining potassium requirements.
- Triticale can be sensitive to potassium deficiency and responses to its application.
- Potassium deficiency is an emerging issue in northern cropping soils.
- It is important to maintain adequate potassium in soil as once symptoms of deficiency emerge, costly fertiliser applications will be required. [63]
- 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 the stomata, the breathing holes on plant leaves that control moisture loss from the plant. Potassium increases vigour and disease resistance of plants, and helps them to form and move starches, sugars and oils. Available potassium exists as an exchangeable cation associated with clay particles and humus. [64]

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

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

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

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

63 Soilquality.org (2017) Potassium, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/potassium-queensland

64 R Quinlan, A Wherrett, S Alt (2017) Potassium, NSW. Soilquality.org, http://www.soilquality.org.au/factsheets/potassium-nsw

65 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), 704–716.

application of different levels of N affected grain protein of triticale, but using different amounts of K did not. [66]

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 (soils low in OM) and with high rainfall, especially where hay is cut and removed regularly.

Factors such as soil acidity, soil compaction and waterlogging will modify root growth and the ability of crops to extract subsoil K. [67]

High potassium:sodium (K: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. [68]

MORE INFORMATION

Mineral supplements needed when grazing cereals

Potassium deficiency in northern soils

Throughout Queensland's cropping regions there has been a gradual decline in soil potassium levels due to crop removal of K and low application rates of K fertiliser. In particular, grain growers on red Ferrosol soils in the inland Burnett region have increasingly encountered potassium deficiency over the last 10 years or so, due to reserves in these soils running down. The problem is also becoming increasingly evident on medium-heavy cracking clay soils. Cotton, legumes and hay baling–silage systems have had a particularly high impact on potassium reserves in some soils.

Crops may vary in their response to potassium fertiliser application and, in winter cereals, responses are generally low unless large deficiencies are present. However, while significant soil potassium reserves still exist in many Queensland cropping soils, particularly the heavier alluvial and cracking clay soils, it is important to maintain soil reserves by replacing the potassium removed in harvested products. If potassium is allowed to be depleted to such an extent that crop productivity is affected, heavy and very costly fertiliser applications will be required. [69]

5.8.1 Symptoms of Potassium 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 9). [70]
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease.
- Sandy areas in the paddock.

What to look for in the plant

- Plants appear paler, and weak and floppy (Photo 10).
- 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.

66 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.

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

68 L Bell, H Dove (2012) Mineral supplements needed when grazing cereals. Ground Cover. Issue 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

69 Soilquality.org (2017) Potassium, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/potassium-queensland

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

- Plants are stunted and spindly
- Small seed size.

Photo 9: *vvThere are fewer symptoms of K deficiency in header rows.*

Source: DAFWA

Photo 10: *Potassium-deficient plants may display floppy older leaves and furled flag leaf from water stress.*

Source: DAFWA

What else it could be

The symptoms described above may be due to other issues (Table 12).

Table 12: *Other 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 alsvo scorch crops. [71]

5.8.2 Managing potassium

Soil and plant-tissue analyses 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 the soil's texture (Table 10).

Table 13: *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, http://www.soilquality.org.au/factsheets/potassium-nsw

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. Northern cropping soils are more likely to be deficient in Zn, Cu, and Mn than the other trace elements.

Of these three, Zn deficiency is probably the most important in the Northern region 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.

Triticale grows productively on alkaline soils where certain trace elements are deficient enough that they will not be suitable for other cereals. [73]

In early trials, it was reported that triticale commonly expressed the Cu efficiency trait derived from its cereal rye parent (i.e. can perform better than many other crops on small amounts of Cu because it uses the element so efficiently), and had efficiency traits for Zn and Mn. Triticale usually performs remarkably well on highly calcareous soils which are often deficient in Mn and Zn and sometimes in Cu. [74]

MORE INFORMATION

Detecting and managing trace element deficiencies in crops

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

Micronutrients and trace elements

What is missing? Identifying and managing trace element deficiencies

Better fertiliser decisions for crop nutrition

5.9.1 Manganese

Manganese helps with photosynthesis. It is freely available in the north-coast NSW acid soils but can be deficient in sandy soils. Manganese deficiency in cereals is widespread. The availability of Mn in soil is strongly related to soil pH. Soils with higher pH have lower Mn availability than soils with lower pH. Mn deficiency is therefore more likely to be a problem on alkaline soils. However, responses to Mn have also been recorded on impoverished, acid to neutral sandy soils.

The availability of Mn is also strongly affected by seasonal conditions and the availability is lowest during a dry spring. Transient Mn deficiency may also appear during cold, wet conditions but affected plants are often seen to recover following rains in spring when soil temperatures are high. Manganese deficiency is

73 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/docrep/009/y5553e/y5553e00.htm

74 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

exacerbated by dry soil, high soil pH, alkaline fertilisers and root pruning herbicides (particularly Groups A and B).

Symptoms of Manganese 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 11). [75]
- Areas of the paddock that are strongly alkaline, poorly drained or in areas with strongly acidic sandy soils.

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 12).
- 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.

Photo 11: *Patches of pale, floppy plants in otherwise healthy crop.*

Source: DAFWA

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

Photo 12: *Middle leaves are affected first, and show yellowing and necrosis.*

Source: DAFWA

What else it could be

The symptoms described above may also be due to other issues (Table 14).

Table 14: *Other problems of triticale that could be confused for manganese 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

- Seed treatments and foliar sprays are available to treat manganese deficiency.

- Consider using acidifying ammonium nitrogen fertilisers, which can reduce manganese deficiency by lowering pH and making manganese more available to growing crops.
- Consider manganese fertiliser, which is effective but expensive, as high rates and several applications are required to generate residual value. [76]

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 has 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. 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. [77]

Where soils are high in manganese (typical of many soils in Australia) many triticale cultivars carry tolerance, and therefore can grow well. [78] Manganese is freely available in northern coastal NSW acid soils, often in toxic amounts in very acid soils. Toxicity is remedied with lime.

5.9.2 Copper

Copper is necessary for carbohydrate and nitrogen metabolism, with inadequate Cu resulting in stunting. Copper is also required for lignin synthesis which is needed for cell wall strength and the prevention of wilting. Deficiency symptoms of Cu are dieback of stems, yellowing of leaves, stunted growth and pale green leaves that wither easily. Copper deficiencies are mainly reported in sandy soils, which are low in organic matter. Copper uptake decreases as soil pH increases. Increased phosphorus and iron availability in soils decreases copper uptake by plants. [79]

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. [80]

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

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

77 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

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/docrep/009/y5553e/y5553e00.htm

79 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

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

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, 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. [81]

Symptoms of Copper 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 13). [82]
- 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, acidic soils, organic alkaline 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 14).
- 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.

81 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.

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

Photo 13: *Pale, necrotic flag leaf at head emergence.*

Source: DAFWA

Photo 14: *Partly sterile head and twisted flag leaf.*

Source: DAFWA

What else it could be

The symptoms described above may also be caused by other issues (Table 12).

Table 15: *Other 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. Where required, copper is normally applied with the fertiliser at 1–2 kg/ha every 3–6 years.
- 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. [83]

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:

- 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).

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. [84]

Although plants do need 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. [85]

5.9.3 Zinc

Zinc helps in the production of a plant hormone responsible for stem elongation and leaf expansion. It is readily available in acid soils, but combines easily with iron in the north-coast NSW red soils. This is easily cured with the addition of zinc sulfate or crushed zinc minerals. Deficiencies of zinc (Zn) are well known in all cereals and cereal-growing countries, and deficiency is a nutritional constraint for crop production

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

84 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

85 Agriculture Victoria (2008) Trace elements for dryland pastures. Note AG0265. Revised. Agriculture Victoria, http://apo.org.au/system/files/57108/apo-nid57108-98416.htm

in Australia, being particularly widespread in cereals growing on calcareous soils common in much of the Northern region. Physiological evidence suggests that a critical level of zinc must be present in the soil before roots will either grow into it or function effectively.

Triticale is thought to have a high tolerance to Zn deficiency compared to wheat, and is second only to cereal rye, which is a very resistant crop to Zn deficiency. [86]

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. [87]

Zinc-use efficiency is highest in rye, and declines (in descending order) in triticale, bread wheat, and durum wheat (Figure 5). The differences in expression of Zn efficiency are possibly related to a greater capacity of efficient genotypes to acquire Zn from the soil compared to inefficient genotypes. [88]

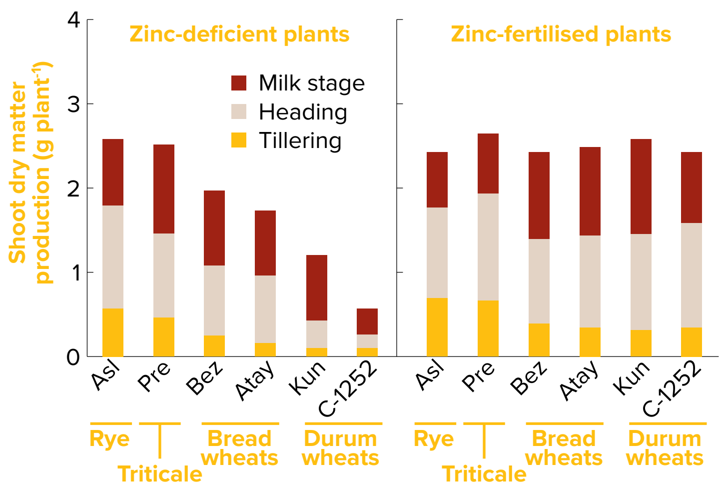

Figure 5: *Dry-matter production of different cereals grown in a field experiment without and with Zn fertilisation in a Zn-deficient calcareous soil. (ASL is Aslim, PRE is Presto, BEZ is Bezostaja-1, ATAY is Atay-85, KUN is Kunduru-1149.) Fertiliser was applied at the rate of 23 kg Zn/ha-1. Plants (main tillers) were sampled at the stages of tillering (105 DAJF), heading (144 DAJF) and milk (168 DAJF), where DAJF stands for days after January 1.*

Source: Cakmak et al. 1997

Symptoms of Zinc deficiency

What to look for in the paddock

- Patchy growth of stunted plants with short, thin stems and usually pale green leaves.

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86 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/docrep/009/y5553e/y5553e00.htm

87 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.

88 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.

- 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.

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 15). [89]
- Maturity is delayed. [90]

Photo 15: *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

The symptoms described above may also be due to other issues (Table 16).

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

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

Table 16: *Other 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 starter fertiliser blend.
- 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 as the dressing can provide the seeds full requirement.
- Zinc present in compound fertilisers often meets the current requirements of the crop. [91]

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. Zinc responses on pasture are rare, but where required zinc should be applied at about 1–2 kg/ha, every 5–6 years. [92]

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 MAP products 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 and has become available recently is the application of liquid 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). [93]

Soil application (pre-plant) - Applying 15–20 kg/ha of zinc sulphate monohydrate 3–4 months before planting should meet the total plant requirement for 5–8 years. Zinc is not mobile in the soil and needs to be evenly distributed over the soil surface, and then thoroughly cultivated into the topsoil. In the first year, a foliar zinc spray may also be required.

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

92 Agriculture Victoria (2008) Trace elements for dryland pastures. Note AG0265. Revised. Agriculture Victoria, http://apo.org.au/system/files/57108/apo-nid57108-98416.htm

93 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

Soil application (at planting) - Banding zinc with phosphorus at planting is an efficient means of delivering zinc to the plants roots. Water injection with either zinc monohydrate or zinc heptahydrate may also be an option for some growers. If applied as a starter fertiliser component, the amount should be at least 1 kg of zinc/ha (about 40 kg/ha of product) which will only provide enough zinc for that crop.

Seed dressing may provide sufficient Zn to meet crop requirement, but will not build up residual zinc to the soil. May be a cost-effective option where soil P levels are adequate.

Foliar sprays - Two applications are necessary. Apply at three weeks and again at five weeks after emergence. It is important both sprays be applied before the crop is six weeks old. The most economical form of foliar zinc is a tank-mix of 1 kg zinc sulphate heptahydrate/ha plus 1 kg urea/ha in 100 L water/ha plus surfactant at 100 mL of 1000 g/L product/100 L of spray mixture (or 160 mL of 600 g/L product/100 L of spray mixture).

Water high in carbonate will produce insoluble zinc carbonate. Consider having the water analysed for suitability in crop protection programs and using a commercial buffering agent.

Zinc heptahydrate sprays may not be compatible with herbicides. Several chelate forms of zinc are available which are generally more compatible with herbicides. Always read the label to determine compatibility. [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 Iron deficiency

What to look for in the paddock

- Pale plants, particularly in waterlogged or limed areas (Photo 16). [96]
- Where the soil type is alkaline, or acidic soils with excessive levels of soluable manganese.

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 17).
- 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 Queensland Department of Agriculture and Fisheries (2012) Wheat–nutrition. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition

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 16: *Pale green to yellow plants may indicate an iron deficiency.*

Source: DAFWA

Photo 17: *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

The symptoms described above can also be caused by other issues (Table 14).

Table 17: *Other 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 Paddock nutrition

Key points:

- Growers can minimise fertiliser inputs by optimising plants' use of pre-existing reserves of soil nutrients.
- Maximising root abundance and rooting depth means that roots can take advantage of nutrients and water in the subsoil.
- Use of soil reserves of nitrogen can be optimised by testing for the different forms of nitrogen and using these figures conduct a N budget.
- Good yield estimates are critical when estimating nutrient requirements.

One way to optimise plant uptake of nutrient reserves in soil is to maximise root abundance and rooting depth. A bigger root system gives plants access to more soil and ensures they can follow nutrients and water down the soil profile. This is especially important for leachable nutrients such as nitrogen and sulfur, and where there are nutrients with significant reserves in the subsoil. Root abundance and rooting depth can be increased by maintaining optimum soil pH and minimising soil compaction and plant root diseases.

Nutrient availability is optimised in soils with topsoil pH levels are in the optimum range of pH 6.0–7.5 ($CaCl_2$). Maintaining the pH above 5.2 in the subsurface will prevent aluminium toxicity, which restricts root growth down the soil profile (Photo 18). [98]

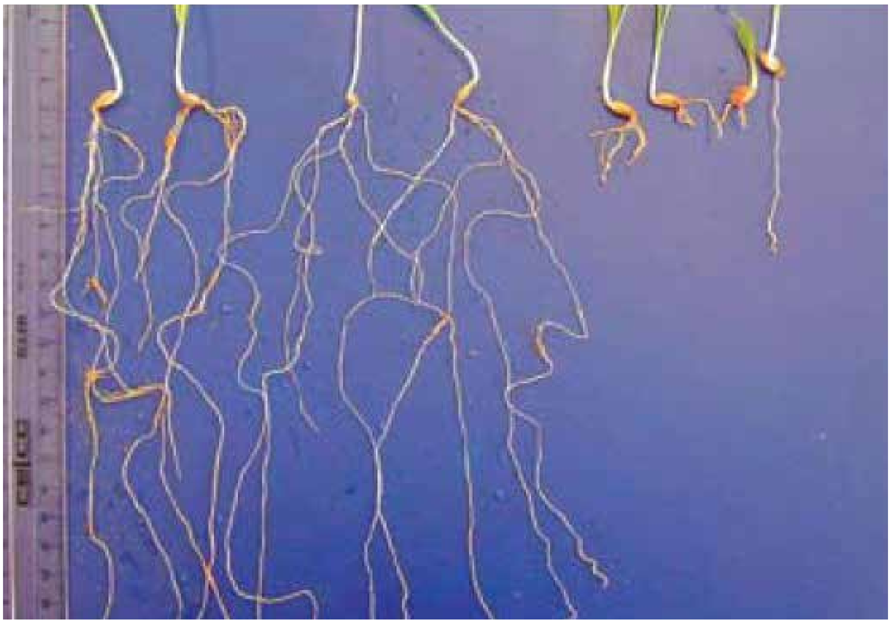

Photo 18: *Roots of cereal grown in acidic subsurface soil (right) are shortened by aluminium toxicity.*

Source: Soilquality.org

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

98 Soilquality.org (2017) Optimising soil nutrition, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland

The application of agricultural lime is an effective way of managing soil acidity and maintaining appropriate soil pH.

Subsoil compaction can reduce the rooting depth of plants by slowing the rate of root penetration. This means roots are unable to access subsoil moisture and leachable nutrients such as nitrogen, and can result in poor nitrogen-use efficiency. Avoiding traffic on the site when soils are moist or wet, restricting traffic to defined wheel tracks (controlled-traffic farming) and minimising the amount of tillage all help to reduce or avoid subsoil compaction.

Plant-root diseases and pathogens can severely decrease root exploration and nutrient uptake. Root lesion nematodes and crown rot are common in Northern cropping regions.

The use of break crops to prevent the build-up of disease and pathogens, growing tolerant crops to maximise yield when nematodes or diseases are present, and practicing good farm hygiene are some of the most effective strategies to manage plant-root pathogens and diseases. [99]

For more information on cereal root disease, see Section 8: Nematode Control, and Section 9: Diseases.

5.10.1 Aluminium toxicty

At soil pH levels of below 5, aluminium (Al) and manganese (Mn) become available in soil solution, and can damage root growth and reduce yields. Screening work in flow-culture systems and field observations has indicated that triticale has a range of tolerances to aluminium [100] but it generally has a higher tolerance to aluminium than other cereals.

Triticale grows productively on acidic soils where the high availability of aluminium ions reduces the economic yield of many other crops. [101]

Many triticale cultivars are able to grow better than wheat in high aluminium toxicity soils. [102]

Many of the new varieties have been screened in flow cultures for Al tolerance (Table 15). In the screening system small plants are given an aluminium stress in solution and afterwards examined for root regrowth. The presence of regrowth and its length indicate relative tolerance, with greater length of regrowth being a measure of greater Al tolerance. As expected, the wheat variety (Janz) had poor tolerance, rye was tolerant, and there was a range of tolerances within the triticales, with Canobolas⁽ᴅ being the most Al-tolerant variety. [103]

99 Soilquality.org (2017) Optimising soil nutrition, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland

100 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

101 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/docrep/009/y5553e/y5553e00.htm

102 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/docrep/009/y5553e/y5553e00.htm

103 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

Table 18: *Aluminium tolerance of triticales.*

Variety	Regrowth length (mm)
Wheat	2.4
Rye	40.6
Tobruk⫏	21.0
JCRT 74	29.5
JCRT 75	30.8
Breakwell⫏	36.5
Tahara	35.1
AT528	27.6
H20	27.6
H55	39.6
H116	29.5
Bogong⫏	29.5
H128	35.4
H157	29.5
H249	32.8
Canobolas⫏	46.1
H426	48.7

Source: Jessop and Fittler 2009