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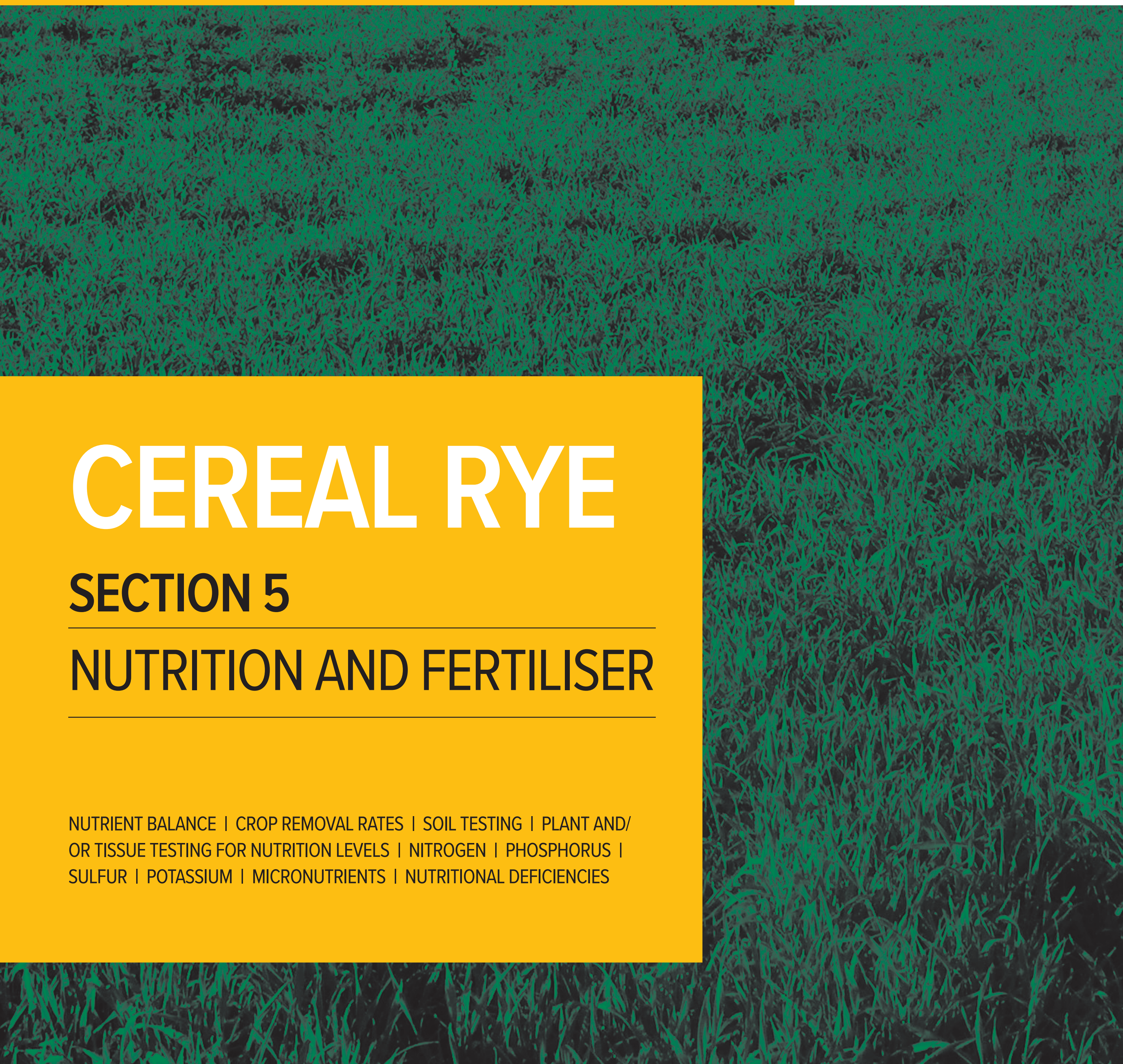

CEREAL RYE

SECTION 5

NUTRITION AND FERTILISER

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

Nutrition and fertiliser

Key messages:

- Only rarely are strong symptoms of nutrient deficiency shown in a cereal rye crop. If symptoms are present, they are likely to be similar to those in wheat. [1]
- Rye can be planted on land that is not fertile enough for crops like wheat.
- Rye can easily be over-fertilised; harvesting can be difficult if the rye lodges from too much nitrogen (N). [2]
- Despite having no taproot, its quick growing, fibrous root system can take up and hold as much as 45 kg of N; however, 12–23 kg is more typical. [3]
- Rye can recycle potassium (K) from deeper in the soil profile for future crop use. [4]
- The northern grain growing region has generally high soil fertility, although there is increasing evidence that this has been run down over time. [5]

5.1 Nutrient balance

Rye is generally more efficient at taking up nutrients than wheat, barley or oats, due to its extensive root system (Table 1).

Table 1: *Mean nutrient uptake of rye at different yield levels.*

	Yield (dt/ha)		
Nutrients	**40 dt/ha**	**60 dt/ha**	**80 dt/ha**
N (kg/ha)	110	150	200
P_2O_3 (kg/ha)	40	60	80
K_2O (kg/ha)	75	115	150
MgO (kg/ha)	15	22	30
CaO (kg/ha)	15	22	30
S (kg/ha)	10	15	20
B (kg/ha)	40	45	50
Cu (kg/ha)	30	40	50
Zn (kg/ha)	120	150	200
Mn (kg/ha)	350	400	600

Source: Schlegel, 2013 [6]

Trials in poor-quality soil have found that cereal rye cropping over three years increased soil organic carbon (SOC) in the topsoil by 27.8% in 2013 and 16.7% in 2014. This represents a total improvement of 47% since 2012 (Figure 1). [7]

1 M Wurst, R Brennan (2007). Winter cereal nutrition—the Ute Guide. Grains Research and Development Corporation, May 2007, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

2 UVM (2011) Cereal rye. University of Vermont, April 2011, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

3 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, March 2015, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

4 N Rector, T Harrigan, DR Mutch, S Snappe (2009) Cereal rye: manure and livestock's new best friend. Manure $ense. Michigan State University, February 2009

5 J Carson. Biological inputs—northern grain-growing region. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/biological-inputs-northern-grain-growing-region

6 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

7 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, March 2015, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

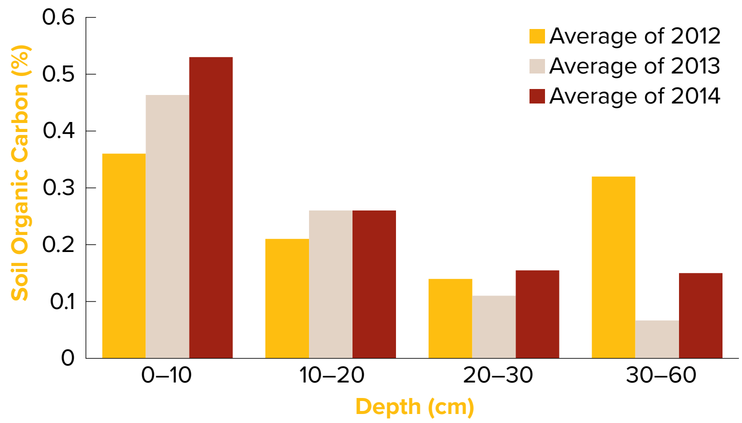

Figure 1: *Percentage average soil organic carbon sampled from four depths in three years.*

Source: Liebe Group

MORE INFORMATION

Liebe Group: Growing cereal rye to increase carbon and prevent wind erosion.

5.1.1 Nutrient benefits from rye

Rye improves water quality because the plant's extensive root system takes up excess soil N that would otherwise leach to contaminate groundwater or surface water bodies. This N is taken up by the plant, and then it slowly becomes available to subsequent crops as the residues gradually decompose.

Rye roots can also extract K and other nutrients from deep in the soil profile and bring them to the surface, where they become available to subsequent crops. Expect considerable fertility improvement in the topsoil when growing rye as a catch crop. [8]

According to long-term trials in the United States, cover crops on average can reduce N loading by 28% and phosphorus (P) loading by 50%. Since 2008, 46 site-years have been conducted, with farmers reporting that in 42 of 46 site-years, properly managed cover crops had little or no negative effect on maize and soybean yield (and actually increased soybean yield in four site-years). [9]

A rye cover crop and manure applications are mutually beneficial. Manure nutrients aid in decomposition of the rye, offsetting any potential yield drag, and rye captures and recycles the manure nutrients effectively to future crops, reducing commercial fertiliser needs. [10]

IN FOCUS

Winter cover crop effects on soil organic carbon in soil

Winter cover crops may increase SOC levels or reduce their rate of depletion. Selection of appropriate cover crops to increase SOC requires an adequate knowledge of the quality and quantity of plant biomass produced and its rate of decomposition in soil. This study examined the SOC and carbohydrate concentrations in soil as affected by several leguminous and non-leguminous cover crops in a temperate, humid region of the United States. The cover crops had a variable effect on SOC and soil carbohydrate concentrations due to a significant difference in total

8 H Valenzuela, J Smith (2002) Rye. Sustainable Agriculture Green Manure Crops. University of Hawai'i, August 2002, http://www.ctahr.hawaii.edu/oc/freepubs/pdf/GreenManureCrops/rye.pdf

9 S Gailans (2015). Winter cereal rye cover crop effect on cash crop yield: results from long-term, on-farm research. Synergy in Science: Partnering for Solutions Conference, Minneapolis, 15–18 November 2015, https://scisoc.confex.com/scisoc/2015am/webprogram/Paper91725.html

10 N Rector, T Harrigan, D Mutch, S Snapp (2010) Cereal rye: manure and livestock's new best friend. Michigan State University

organic C and carbohydrate produced by the cover crops. The overriding cover crop effect on SOC and carbohydrate was due to the magnitude of the C inputs from the cover crops. With more than 4 t/ha of top biomass, cereal rye and annual ryegrass were better suited as winter cover crops for building SOC levels in this study than Austrian winter pea, hairy vetch, and canola. [11]

VIDEOS

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

WATCH: Improving phosphate use efficiency.

5.1.2 Fertiliser application

Winter rye and winter wheat respond similarly to nutrient additions. Soil tests are the best guide on which to base fertiliser rates. Phosphorus should be applied in autumn although improved efficiency can be achieved by banding phosphate directly below the seed at planting, especially on high pH soils. The N application should be split, especially on lighter soils with one part applied at planting, and the rest by topdressing in the spring.

Rye should be fertilised when grown for pasture or as a cover crop. Early application of N and P increases early growth, which improves winter groundcover. A spring topdressing with N is desirable where rye is pastured. Heavy N applications promote lodging in rye grown for grain. A moderate rate of manure is a good general fertiliser. [12]

Most varieties of cereal rye do not require any more fertiliser than other cereals. However, given its ability to produce winter feed very quickly, strong economic responses can be gained from supplying the crop with a good amount of starter fertiliser (e.g. upwards of 100 kg/ha of di-ammonium phosphate). Follow up with a topdressing of N (30–50 kg/ha) when the crop is at early tillering stages, perhaps three weeks after emergence. Additional fertiliser and lime can be applied according to a soil test. [13]

Recommendations for P fertiliser and, where necessary, N fertiliser are the same as for wheat. Some current recommendations are:

- Apply P at 10–15 kg/ha and N at 10–20 kg/ha at sowing.
- Occasionally N broadcast post-sowing may be required if the crop appears deficient. [14]

5.2 Crop removal rates

Ultimately, nutrients removed from paddocks will need to be replaced to sustain production (Table 2). In irrigated cropping, large quantities of nutrients are removed and growers need to adopt a strategy of programmed nutrient replacement, but dryland growers should also consider this approach. The yield potential of a crop will be limited by any nutrient the soil cannot adequately supply. Temperature and soil moisture content will affect the availability of nutrients to plants, as will soil pH, degree of exploration of root systems and various soil chemical reactions, which vary from soil to soil. Fertiliser may be applied in the top 5–10 cm, but unless the soil remains moist, the plant will not be able to access it. Movement of nutrients within the soil profile in low-rainfall areas is generally low except in very sandy soils.

11 S Kuo, UM Sainju, EJ Jellum (1997) Winter cover crop effects on soil organic carbon and carbohydrate in soil. Soil Science Society of America Journal, 61(1), 145–152, https://dl.sciencesocieties.org/publications/sssaj/abstracts/61/1/SS0610010145?access=0&view=pdf

12 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Rye. In Alternative field crops manual. University of Wisconsin and University of Minnesota, https://hort.purdue.edu/newcrop/afcm/rye.html

13 Wrighton Seeds. Forage focus—southern green ryecorn. http://www.pggwrightsonseeds.com.au/products/cereals/southerngreenryecorn/

14 R Sonogan (2013) Growing cereal rye. Agriculture Victoria, May 2013, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Lack of movement of nutrients combined with current farming methods (e.g. no-till) results in stratification of nutrients, whereby nutrient concentrations build up in the surface of the soil where they are not always available to plants, depending on the seasonal conditions. On the Western Downs and in Central Queensland, cereals are often deep-sown in moisture that is below the layer where nutrients have been placed or are stratified, which has implications for management and fertiliser practices. [15]

Table 2: *Estimated nutrient removal rates (kg/ha) for cereal rye grain and straw.*

Cereal rye	Yield per ha	Nitrogen	Phosphorus pentoxide	Potassium oxide	Calcium	Magnesium	Sulfur	Copper	Manganese	Zinc
Grain	1.88 t	39	11	11	2.2	3.4	7.9	0.022	0.25	0.034
Straw	3.36 t	17	9	28	9	2.2	3.4	0.011	0.16	0.079

Source: converted from North Caroline State University

5.3 Soil testing

Key points:

- A soil test critical value is the soil test required to achieve 90% of maximum potential crop yield.
- A range of soil test values used to determine whether a nutrient is deficient or adequate is termed a critical range. The critical range reflects the degree of uncertainty around the critical value.
- Fertiliser decisions are in part based on where the soil test falls in relation to the critical range.
- Critical ranges for combinations of nutrient, crop and soil types are being established.
- Critical ranges are being established for topsoils (0–10 cm) and subsoils (10–30 cm in some cases, or to the depth of the crop root-zone in others) depending on the nutrient.
- Deeper sampling is considered essential for understanding soil nutritional status and fertiliser requirement in northern cropping systems.

In northern cropping soils, nutrient deficiencies other than N are a relatively recent development. Consequently, there has been less nutrient research conducted in these soils and on the many crop types grown in northern cropping systems. Most research has been done on N in wheat and barley.

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

The importance of subsoil layers for nutrients such as P and K is not yet reflected in the limited soil test–crop response data available. Researchers are using rules-of-thumb to help interpret P and K soil tests in terms of likely fertiliser responsiveness on northern region Vertosols.

These figures are still 'works in progress' and will be refined as more nutrient information comes to light during this second phase of the More Profit from Crop Nutrition program. [16]

5.3.1 Why test soil?

Soil testing may be carried out for various purposes such as:

- assessment of land capability for various forms of agriculture

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

16 GRDC (2014) Crop nutrition fact sheet: soil testing crop nutrition, northern region. Grains Research and Development Corporation, January 2014, www.grdc.com.au/GRDC-FS-SoilTestingN

- identifying and quantifying soil constraints (e.g. salinity)
- monitoring of soil fertility levels
- providing guidelines as to the type and amount of fertiliser to be applied for optimum plant growth on the particular site
- as a diagnostic tool to help identify reasons for poor plant performance.

The ultimate aim is to reduce the guesswork involved in managing a specific area of a crop. However, the results and recommendations may be worthless, or even misleading, if sampling and/or analysis of submitted samples are not carried out properly or if subsequent interpretation of the data is flawed.

MORE INFORMATION

QDAF: Soil nutrient testing: how to get meaningful results

GRDC Fact Sheet: Soil testing for crop nutrition—northern region.

VIDEOS

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

5.3.2 Basic requirements

Three basic steps must be followed if meaningful results are to be obtained from soil testing:

1. Take a representative sample of soil for analysis.
2. Analyse the soil by using the accepted procedures that have been calibrated against fertiliser experiments in that particular region.
3. Interpret the results using criteria derived from those calibration experiments.

Each of these steps may be under the control of a different person or entity. For example, the sample may be taken by the farmer manager or 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]

5.3.3 Types of test

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

- bicarbonate-extractable P (Colwell P)
- bicarbonate-extractable K (Colwell K)
- KCl-40 extractable S
- 2 M 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-absorption capacity (measured as P buffering index, PBI), electrical conductivity, chloride, and cation exchange capacity (CEC) including aluminium.

5.4 Plant and/or tissue testing for nutrition levels

5.4.1 Why measure nutrients in plant tissues?

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

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

17 D Loch. Soil nutrient testing: how to get meaningful results. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/__data/assets/pdf_file/0006/65985/Soil-Nutrient-Testing.pdf

5.4.2 What does plant tissue analysis show?

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

Although usually used as a diagnostic tool for future correction of nutrient problems, plant tissue analysis from young plants (Table 3) will allow a corrective fertiliser application that same season. A plant tissue analysis can pinpoint the cause, if it is nutritional.

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

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

Sampling tips:

- 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 sufficiently large sample quantity (adhere to guidelines for each species provided).
- When troubleshooting, take separate samples from good and poor growth areas.
- Wash samples while fresh where necessary to remove dust and foliar sprays.
- Keep samples cool after collection.
- Refrigerate or dry if samples cannot be dispatched to the laboratory immediately to arrive before the weekend.
- Where possible sample in the morning while plants are actively transpiring.

Practices to avoid:

- sampling spoiled, damaged, dead or dying plant tissue
- sampling plants stressed by environmental conditions
- sampling plants affected by disease, insects or other organisms
- taking samples soon after applying fertiliser to the soil or foliage
- contaminating samples with dust, fertilisers or chemical sprays, or perspiration or sunscreen from hands
- sampling from atypical areas of the paddock, e.g. poorly drained areas
- sampling plants of different vigour, size and age
- combining samples from different cultivars (varieties) to make one sample
- placing samples into plastic bags, which will cause the sample to sweat and hasten its decomposition
- sampling in the heat of the day, i.e. when plants are moisture stressed
- mixing leaves of different ages. [18]

18 SoilMate (2010) Guidelines for sampling plant tissue for annual cereal, oilseed and grain legume crops. Back Paddock, http://www.backpaddock.com.au/assets/Product-Information/Back-Paddock-Sampling-Plant-Tissue-Broadacre-V2.pdf?phpMyAdmin=c59206580c88b2776783fdb796fb36f3

Table 3: *Plant tissue requirements for nutrient testing in wheat or triticale.*

Growth stage (Zadoks) to sample	Plant part	Number required
Seedling to early tillering (Z14–21)	Whole shoots cut off 1 cm above ground	40
Early tillering to 1st node (Z23–31)	Whole shoots cut off 1 cm above ground	25
Flag leaf ligule just visible to boots swollen (Z39–45)	Whole shoots cut off 1 cm above ground	25
Early tillering to 1st node (Z21–31)	Youngest expanded blade plus next two lower blades	40

Source: BackPaddock

5.5 Nitrogen

Key points:

- Rye is one of the best scavengers of N and reduces leaching losses on both sandy soils and tile-drained land.
- Nitrate is the highly mobile form of inorganic N in both the soil and the plant.
- Sandy soils in high rainfall areas are most susceptible to nitrate loss through leaching.
- Nitrogen is needed for crop growth in larger quantities than any other nutrient.
- Soil testing and N models will help determine seasonal N requirements.

The two forms of soil mineral N absorbed by most plants are nitrate and ammonium (Figure 2). In well-aerated soils during the growing season nitrate becomes the main form of N available for crops as microbial activity quickly transforms ammonium into nitrate. It is crucial to keep nitrate at adequate levels: too little can limit crop production and too much can lead to environmental pollution. The levels of soil nitrate vary over space and time. Proper agricultural management needs to consider both site-specific variations and temporal patterns in soil nitrate to supply optimum amounts from both organic and mineral sources. [19]

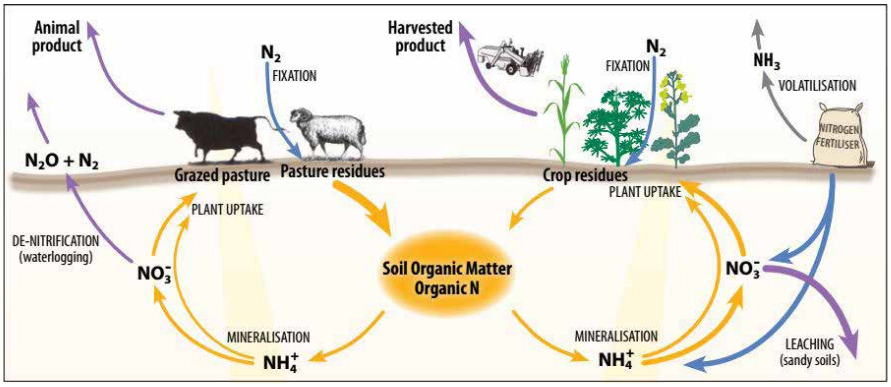

Figure 2: *Principal nitrogen cycling pathways in a mixed cropping/pasture system (adapted from Peverill et al. 1995 20).*

Source: Soil Quality Pty Ltd

The ability of rye to affect soil N levels can depend on topography. In one study, rye cover crop had a significant 15% negative effect on nitrate in topographical depressions but not in slope and summit positions. [21]

19 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, e0143358, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0143358

20 KI Peverill, LA Sparrow, DJ Reuter (1995) Soil analysis: an interpretation manual. CSIRO Publishing.

21 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, e0143358, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0143358

IN FOCUS

Accumulation and loss of nitrogen during growth and maturation of cereal rye

The loss of total N from herbage of cereal rye after anthesis was studied by recovering herbage, roots, and anthers of rye grown in soil (under dryland conditions), nutrient solution, and sand culture. The amount of N in herbage of dryland rye decreased an average of 7.9 kg/ha during the two weeks following anthesis. Potential loss of N from herbage through shedding of anthers and pollen was estimated at 16 kg/ha. Rye grown in sand or solution culture continued to absorb and accumulate N after anthesis which masked the N lost during anthesis. We found no evidence to suggest transport of N from herbage to roots under either dryland conditions, or sand or nutrient culture. [22]

Rye will often respond to a modest application of N fertiliser, but when it follows crops that have been well fertilised with N it seldom requires additional fertiliser. Rye has a good ability to scavenge residual soil N when it follows other crops, and it is commonly grown for this purpose. This reduces the potential for nitrate leaching into groundwater and it conserves N fertiliser inputs, which saves money. [23]

The amount of N safely placed with the seed will vary depending on soil texture, amount of seedbed utilisation and moisture conditions. Greater amounts of N can be safely applied with the seed if it is a polymerised form of urea where the N is released over a period of several weeks. If soil moisture is marginal for germination, high rates of fertiliser should not be placed with the seed. Both N and P can be banded prior to seeding, but take care to avoid loss of seedbed moisture and protective crop residue. [24]

IN FOCUS

Nitrate leaching under a cereal rye cover crop.

Winter cover crops hold potential to capture excess nitrate and reduce leaching by recycling nutrients. A study in Oregon, USA, compared winter nitrate leaching losses under winter fallow and a cover crop of winter cereal rye. Leachate was sampled with passive capillary wick samplers. This cover crop–crop rotation study, initiated in 1989, had a cropping system (winter fallow *v.* winter cereal rye) as main plots, and three N application rates, ranging from 0 to 280 kg N/ha/year, as subplots. At the recommended N rate for the summer crops, nitrate leaching losses in winter were 48 kg N/ha under sweet corn–winter fallow in 1992–93, 55 kg N/ha under broccoli–winter fallow in 1993–94, and 103 kg N/ha under sweet corn–winter fallow in 1994–95, which were reduced to 32, 21, and 69 kg N/ha, respectively, under winter cereal rye. For the first two winters, 61% of the variation in nitrate leaching was explained by N rate (29%), cereal rye N uptake (17%), and volume of leachate (15%). Seasonal, flow-

22 CB Rumburg, FA Sneva (1970) Accumulation and loss of nitrogen during growth and maturation of cereal rye (*Secale cereale*). *Agronomy Journal* 62, 311–313.

23 V Grubinger (2010). Winter rye: a reliable cover crop. University of Vermont, October 2010, https://www.uvm.edu/vtvegandberry/factsheets/winterrye.html

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

weighted concentrations at the recommended N rate were 13.4 mg N/L under sweet corn–winter fallow (1992–93), 21.9 mg N/L under broccoli–winter fallow, and 17.8 mg N/L under sweet corn–winter fallow (1994–95), and these were reduced by 39%, 58%, and 22%, respectively, under winter cereal rye. [25]

5.5.1 Nitrogen deficiency symptoms in cereals

What to look for

Paddock:

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

Plant:

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

25 FM Brandi-Dohrn, M Hess, JS Selker, RP Dick, SM Kauffman, DD Hemphill (1997) Nitrate leaching under a cereal rye cover crop. *Journal of Environmental Quality* 26, 181–188, https://dl.sciencesocieties.org/publications/jeq/abstracts/26/1/JEQ0260010181

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

Source: Department of Agriculture and Food Western Australia

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

Source: Department of Agriculture and Food Western Australia

VIDEOS

WATCH: GCTV14: Nitrogen deficiency.

Deficiency symptoms can be treated with N fertiliser or foliar spray. NOTE: There is a risk of volatilisation loss from urea or ammonium sources of N on alkaline soils when topdressed on dry soils in dewy conditions. Losses rarely exceed 3% per day. [26]

What else could it be?

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 of K-deficient plants. Tillering is less affected
Molybdenum deficiency	Pale poorly tillered plants	Molybdenum deficiency affects the middle leaves first and cause white heads, shrivelled grain and delayed maturity

5.6 Phosphorus

Key points:

- Phosphorus is one of the most critical and limiting nutrients in agriculture in the northern cropping region.
- Phosphorous cycling in soils is complex.
- Only 5–30% of P applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus fertiliser is best applied at seeding.
- Phosphorus is the most generally used fertiliser for rye. The rate of P application varies in the range 6–18 kg/ha, lighter applications being used in drier districts. [27]

Phosphorus is essential for plant growth, but few Australian soils have enough P for sustained crop and pasture production. Complex soil processes influence the availability of P applied to the soil, with many soils able to adsorb or 'fix' P, making it less available to plants (Figure 3). A soil's ability to fix P must be measured when determining requirements for crops and pastures. [28]

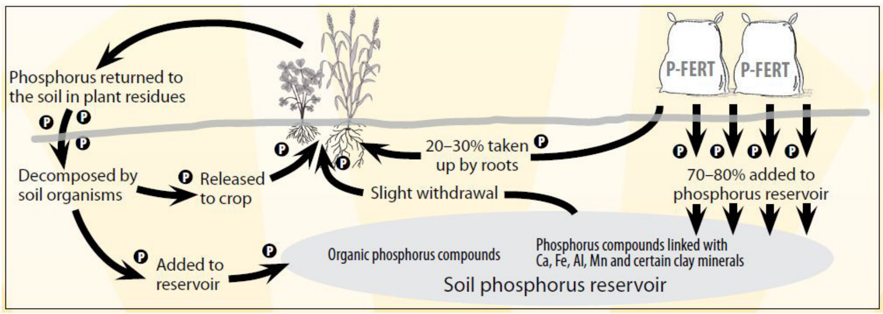

Figure 3: *The phosphorus cycle in a typical cropping system is very complex, where movement through the soil is minimal and availability to crops is severely limited (from Fertiliser Industry Federation of Australia Inc., 2000 29).*

Source: Soil Quality Pty Ltd

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

27 RL Reid (Ed.) (2013). The manual of Australian agriculture. Elsevier, http://www.sciencedirect.com/science/book/9780409309461

28 S Alt (2013) Phosphorus NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/phosphorus-nsw

29 Fertiliser Industry Federation of Australia Inc. (2000) Australian soil fertility manual. (Ed. JS Glendinning) CSIRO Publishing.

IN FOCUS

Uptake and utilisation of phosphate from iron phosphate—rye shows efficiency

Two glasshouse experiments were conducted to evaluate the genotypic variation amongst cereal genotypes in P uptake from relatively insoluble iron phosphate (FePO4). Two rates of iron phosphate were selected representing a deficient and sufficient supply (26 and 339 mg P/kg soil, respectively).These rates were used to screen 99 wheat, eight triticale, and four cereal rye genotypes for P-use efficiency. Phosphorus efficiency was rated by four criteria: shoot dry weight at deficient P supply, shoot weight at deficient supply relative to shoot weight at sufficient P supply, P uptake efficiency (amount of P taken up per unit of P supplied) and P-utilisation efficiency (shoot weight per unit P in plant). No genotypes were rated as efficient under all four criteria. Only two genotypes were rated efficient (rye Bevy, rye PC00361) and one inefficient (wheat Machete) under three criteria. Significant genotypic variation was identified in cereals in the ability to take up and utilise P from poorly soluble iron phosphate, although all genotypes were able to utilise this source of P to some degree. [30]

5.6.1 Managing phosphorus

Place P with or near the seed at seeding time or band prior to seeding. High application rates can lead to both salt burning of the seedlings and a thin plant stand, reducing potential yield. [31]

Rye has been found to be more efficient in taking up and utilising P than wheat at low rates of P supply. [32]

Symptoms

Paddock:

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

Plant:

- In early development, usually in cases of induced P deficiency, seedlings appear to be pale olive green and wilted (Photos 4 and 5).
- 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 remain dark green. Unlike N deficiency, necrosis (death) of these chlorotic (pale) areas is rapid, with the tip becoming orange to dark brown and shrivelling, while the remainder turns yellow. At this stage, the second leaf has taken on the early symptoms of P deficiency.

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30 LD Osborne, Z Rengel (2002) Genotypic differences in wheat for uptake and utilisation of P from iron phosphate. *Australian Journal of Agricultural Research* 53, 837–844, http://www.publish.csiro.au/cp/AR01101

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

32 LD Osborne, Z Rengel (2002) Genotypic differences in wheat for uptake and utilisation of P from iron phosphate. *Australian Journal of Agricultural Research* 53, 837–844, http://www.publish.csiro.au/cp/AR01101

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

Photo 3: *Stunted early growth with reduced tillers in phosphorus-deficient crop on the left.*

Source: Department of Agriculture and Food Western Australia

Photo 4: *Phosphorus-deficient plants on the left are later maturing with fewer smaller heads.*

Source: Department of Agriculture and Food Western Australia

VIDEOS

WATCH: GCTV13: Phosphorus deficiency.

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

Photo 5: *Phosphorus-deficient plants with dark leaves and necrosis moving down from the tip of the oldest leaf.*

Source: Department of Agriculture and Food Western Australia

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

Phosphorus does leach on sands of very low PBI (a measure of P retention), particularly on coastal plains. Topdressing is effective on these soils. [33]

What else could it be?

Nitrogen deficiency, molybdenum deficiency or potassium deficiency

Similarities: Small, less tillered and light green plants.

Differences: Phosphorus-deficient plants are thinner with darker leaves and tip death of older leaves without leaf yellowing.

5.7 Sulfur

Historically, adequate S has been supplied by mineralisation from organic matter, from co-application as a nutrient in N and P fertilisers (sulfate of ammonia and superphosphate) or via the presence of calcium sulfate layers in root-accessible layers of the subsoil.

However, with the increased use of high-analysis N and P fertilisers low in S, deficiency in crops is increasing, especially in wet years due to leaching. Sulfur deficiency appears to be a complex interaction between seasonal conditions, crop

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

species and plant availability of subsoil S. This affects the ability of the soil S test to predict plant-available S. Deficiencies may be more evident in wet years due to S leaching. [34]

Deficiency symptoms

Paddock:

- Look for areas of pale plants (Photo 6).

Plant:

- Plants grow poorly and lack vigour with reduced tillering, delayed maturity and lower yields and protein levels.
- Youngest leaves are affected first and most severely.
- Leaves on deficient plants leaves turn pale with no stripes or green veins but generally do not die and growth is retarded and maturity delayed (Photo 7).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red.

Photo 6: *Areas of pale plants characterise sulfur deficiency (note, however, that many nutrient deficiencies also exhibit pale patches).*

Source: Department of Agriculture and Food Western Australia

34 GRDC (2014) Crop nutrition fact sheet: soil testing crop nutrition, northern region. Grains Research and Development Corporation, January 2014, www.grdc.com.au/GRDC-FS-SoilTestingN

Photo 7: *Leaves remain healthy despite the yellowing in a sulfur-deficient plant.*

Source: Department of Agriculture and Food Western Australia

Topdressing 10–15 kg per hectare of sulfur as gypsum or ammonium sulfate will overcome deficiency symptoms. Foliar sprays generally cannot supply enough sulfur for plant needs. [35]

What else could it be?

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, nitrogen deficiency, molybdenum deficiency or manganese deficiency	Pale growth	The youngest leaves of S-deficient plants are affected first, whereas the middle or older leaves are affected first with waterlogging, manganese, N and molybdenum deficiency

5.8 Potassium

- Potassium deficiency is an emerging issue in northern cropping soils.
- Soil and plant testing is the most effective means of determining K requirements.

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

- It is important to maintain adequate K in soil; once deficiency symptoms emerge, costly fertiliser applications will be required. [36]
- Rye can recycle K from deeper in the soil profile for future crop use. [37]

Potassium is an essential plant nutrient. It has many functions including the regulation of the opening and closing of stomata—the 'breathing holes' on plant leaves that control moisture loss from the plant. Adequate K increases vigour and disease resistance of plants, and helps to form and move starches, sugars and oils. Available K exists as an exchangeable cation associated with clay particles and humus. Rye increases the concentration of exchangeable K near the soil surface by bringing it up from lower in the soil profile.

Potassium deficiency

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

Crops may vary in their response to K fertiliser application, and in winter cereals, responses are generally low unless large deficiencies are present. Although significant soil K 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 K removed in harvested products. If K depletion is allowed to the extent that crop productivity is affected, heavy and very costly fertiliser applications will be required. [38]

What to look for

Paddock:

- Smaller lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows (Photo 8).
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease.

Plant:

- Plants appear paler and weak (Photo 9).
- 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.

36 Soil Quality Pty Ltd. Potassium—Queensland. Soil Quality, http://www.soilquality.org.au/factsheets/potassium-queensland

37 N Rector, T Harrigan, DR Mutch, S Snappe (2009) Cereal rye: manure and livestock's new best friend. Manure $ense. Michigan State University, February 2009

38 Soil Quality Pty Ltd. Potassium—Queensland. Soil Quality, http://www.soilquality.org.au/factsheets/potassium-queensland

Photo 8: *Header rows in potassium-deficient crops have lesser symptoms.*

Source: Department of Agriculture and Food Western Australia

Photo 9: *Potassium-deficient plants may display floppy older leaves and furled flag leaf from water stress. Affected plants are paler, weak and more susceptible to leaf disease. Discoloured leaf tissue can be bright yellow.*

Source: Department of Agriculture and Food Western Australia

Topdressing K will generally correct the deficiency. Foliar sprays generally cannot supply enough K to overcome a severe deficiency and can scorch crops. [39]

What else could it be?

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 K deficiency is more marked in high growth plants in good seasons
Root-lesion nematode	Smaller, water-stressed pale plants	Root-lesion nematode affected plants have 'spaghetti' roots with few feeder roots

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

Assessing potassium requirements

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

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

Potassium available in the soil is measured by the Colwell K or exchangeable K soil tests. The amount of K needed for plant nutrition depends on soil texture (Table 4).

Table 4: *Critical soil test thresholds for potassium (Colwell K, µg/g).*

	Deficient	Moderate	Sufficient
Cereal, canola, lupins etc. [40]	<50	50–70	>70
Pasture legumes [41]	<100 (sand) <150 (clay loam)	100–140 (sand) 150–180 (clay loam)	>140 (sand) >180 (clay loam)

Source: Soil Quality Pty Ltd

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

Potassium lost through product removal should be replaced once K levels in paddocks fall below sufficient 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. [42]

5.9 Micronutrients

Important micronutrients for rye are boron, copper, Fe, manganese, zinc (Zn) and molybdenum. Rye response to micronutrients is generally low, except Zn.

5.9.1 Zinc

Zinc deficiency is a nutritional constraint for crop production in Australia and is particularly widespread in cereals growing on calcareous soil. Rye has a higher Zn-use efficiency than other cereals. Rye possesses exceptional ability to grow and yield well on severely Zn-deficient calcareous soils and it is therefore regarded as Zn-efficient. [43]

Zinc is an essential component of various enzyme systems for energy production, protein synthesis and growth regulation. Zinc-deficient plants exhibit delayed maturity. The most visible Zn-deficiency symptoms are short internodes and a decrease in leaf size. Zinc shortages are mostly found in sandy soils, which tend to be low in organic matter. Deficiency occurs more often during cold, wet conditions and is related to reduced root growth and activity. Zinc uptake by plants decreases with increasing soil pH and is adversely affected by high levels of available P and Fe in soil. [44]

40 RF Brennan, MJ Bell (2013) Soil potassium—crop response calibration relationships and criteria for field crops grown in Australia, Crop & Pasture Science 64, 514–522, http://www.publish.csiro.au/cp/CP13006

41 CJP Gourley, AR Melland, RA Waller, IM Awty, AP Smith, KI Peverill, MC Hannah (2007) Making better fertiliser decisions for grazed pastures in Australia. Department of Primary Industries Victoria, June 2007, http://www.asris.csiro.au/downloads/BFD/Making%20Better%20Fertiliser%20Decisions%20for%20Grazed%20Pastures%20in%20Australia.pdf

42 Soil Quality Pty Ltd. Potassium—NSW. Soil Quality , http://www.soilquality.org.au/factsheets/potassium-nsw

43 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, 1–10, http://link.springer.com/article/10.1023/A:1004247911381

44 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

Deficiency symptoms

Paddock:

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

Plant:

- Young to middle leaves develop yellow patches between the mid-vein and edge of the leaf and extend lengthways towards the tip and base of the leaf. This stripe may occur only on one side of the mid-vein.
- The areas eventually die turning pale grey or brown.
- The leaf changes from green to a muddy greyish-green in the central areas of middle leaves.
- Stunted plants often have 'diesel-soaked' leaves, showing dead areas about halfway along the leaves, causing them to bend and collapse in the middle section (Figure 13).
- Maturity is delayed. [45]

Photo 10: *In zinc-deficient plants, leaves yellow and die and can show a 'tramline effect'. Necrosis halfway along middle and older leaves causes them to droop.*

Source: Department of Agriculture and Food Western Australia

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

What else could it be?

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

IN FOCUS

Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils

Field and greenhouse experiments were carried out to study the response of rye, triticale, two bread wheats, and two durum wheats to Zn deficiency and Zn fertilisation in severely Zn-deficient calcareous soils (DTPA-extractable Zn, 0.09 mg/kg soil). The first visible symptom of Zn deficiency was a reduction in shoot elongation followed by the appearance of whitish brown necrotic patches on the leaf blades. These symptoms were either absent or only slight in rye and triticale, but occurred more rapidly and severely in wheats, particularly in durum wheats. The same was true for the decrease in shoot dry matter production and grain yield. For example, 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% 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 with Zn fertilisation were, on average, 99% for rye, 74% for triticale, 59% for bread wheats and 25% for durum wheats.

These distinct differences among and within the cereal species in susceptibility to Zn deficiency were closely related to the total amount (content) of Zn per shoot, but not related to Zn concentrations in shoot dry matter. For example, the most Zn-efficient rye and the Zn-inefficient durum wheat cultivar C-1252 did not differ in shoot Zn concentration under Zn deficiency, but the total amount of Zn per whole shoot was approximately six-fold higher in rye than the durum wheat. When Zn was applied, rye and triticale accumulated markedly more Zn both per whole shoot and per unit shoot dry matter than wheats.

The results demonstrate an exceptionally high Zn efficiency of rye and show that among the cereals studied, Zn efficiency declines in the order rye > triticale > bread wheat > durum wheat (Figure 4). The differences in expression of Zn efficiency are possibly related to a greater capacity of efficient genotypes to acquire Zn from the soil relative to inefficient genotypes. [46]

46 I Cakmak, H Ekiz, A Yilmaz, B Torun, N Köleli, I Gültekin, A Alkan, S EkerS (1997). Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. *Plant and Soil* 188, 1–10, http://link.springer.com/article/10.1023/A:1004247911381

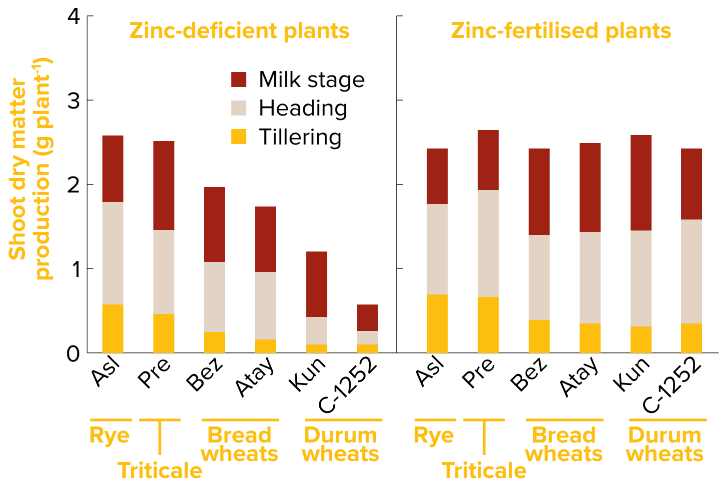

Figure 4: *Dry matter production of different cereals (ASL, Aslim; PRE, Presto; BEZ, Bezostaja-1; ATAY, Atay-85; KUN, Kunduru-1149) grown in the field experiment without and with zinc fertilisation (23 kg Zn/ha) in a Zn-deficient calcareous soil. Plants (main tillers) were sampled at the tillering, heading and milk stages, respectively 105, 144 and 168 days after 1 January.* [47]

Managing zinc deficiency:

- Foliar spray (effective only in current season) or drilled soil fertiliser.
- Zinc foliar sprays need to be applied as soon as deficiency is detected to avoid irreversible damage.
- Zinc is immobile in the soil; therefore, topdressing is ineffective, only being available to the plant when the topsoil is wet.
- Mixing Zn throughout the topsoil improves availability through more uniform nutrient distribution.
- Zinc drilled deep increases the chances of roots being able to obtain enough Zn when the topsoil is dry.
- Zinc seed treatment is used to promote early growth where root disease is a problem, but the level is lower than a plant needs in the current season.
- Zinc present in compound fertilisers often meets the current requirements of the crop. [48]

47 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, 1–10, http://link.springer.com/article/10.1023/A:1004247911381

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

IN FOCUS

Role of rye chromosomes in improvement of zinc efficiency in wheat and triticale

Disomic wheat–rye addition lines (*Triticum aestivum* L., cv. Holdfast–*Secale cereale* L., cv. King-II) and an octoploid triticale line (×Triticosecale Wittmark L. Pluto × Fakon), as well as the respective wheat and rye parents, were used to study the role of rye chromosomes on the severity of Zn deficiency symptoms, shoot dry matter production, Zn efficiency, shoot Zn concentration and Zn content. Plants were grown in a greenhouse in a Zn-deficient calcareous soil with and without Zn supply at 10 mg/kg soil. Zinc efficiency was calculated as the ratio of dry weight produced under Zn deficiency to the dry weight produced under Zn fertilisation. In the experiments with addition lines, visual Zn deficiency symptoms were slight in the rye cv. King-II, but were severe in the wheat cv. Holdfast. The addition of rye chromosomes, particularly 1R, 2R and 7R, into Holdfast reduced the severity of deficiency symptoms. Holdfast showed greater decreases in shoot dry matter production through Zn deficiency and thus had a low Zn efficiency (53%). King-II was less affected by Zn deficiency and had a higher Zn efficiency (89%). With the exception of the 3R line, all addition lines had higher Zn efficiency than their wheat parent: the 1R line had the highest Zn efficiency (80%). In the experiment with the triticale cultivar and its parents, rye cv. Pluto and wheat cv. Fakon, Zn deficiency symptoms were absent in Pluto, slight in triticale and very severe in Fakon. Zinc efficiency was 88% for Pluto, 73% for triticale and 64% for Fakon. Such differences in Zn efficiency were better related to the total amount of Zn per shoot than to the amount of Zn per unit dry weight of shoot. In the rye cultivars, Zn efficiency was closely related to Zn concentration. Triticale was more similar to rye than wheat regarding Zn concentration and Zn accumulation per shoot under both Zn-deficient and Zn-sufficient conditions.

The results show that rye has an exceptionally high Zn efficiency, and the rye chromosomes, particularly 1R and 7R, carry the genes controlling Zn efficiency. [49]

5.9.2 Iron

Iron (Fe) is involved in the production of chlorophyll and is a component of many enzymes associated with energy transfer, N reduction and N_2 fixation, and lignin formation. Iron deficiencies are mainly manifested as yellow leaves due to low levels of chlorophyll. Leaf yellowing first appears on the younger upper leaves in interveinal tissues. Severe Fe 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 Fe-deficient. Cool, wet weather enhances Fe deficiencies, especially in soils with marginal levels of available Fe. Poorly aerated or compacted soils also reduce iron uptake. High levels of available P, manganese and Zn in soils can also reduce Fe uptake. [50]

49 I Cakmak, R Derici, B Torun, I Tolay, HJ Braun, R Schlegel (1997) Role of rye choromosomes in improvement of zinc efficiency in wheat and triticale. *Developments in Plant and Soil Sciences* 78, 237–241, http://link.springer.com/chapter/10.1007%2F978-94-009-0047-9_65

50 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

Symptoms

Paddock:

- Pale plants particularly in waterlogged or limed areas (Photo 11).

Plant

- 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, the interveinal area turns almost white (Photo 12).
- New growth remains yellow for some time before leaves start to die.
- Old leaves remain pale green and apparently healthy.
- Severely affected plants are stunted with thin spindly stems.

Photo 11: *Iron-deficient plants are pale green to yellow.*

Source: Department of Agriculture and Food Western Australia. Photo: courtesy CSIRO Publishing

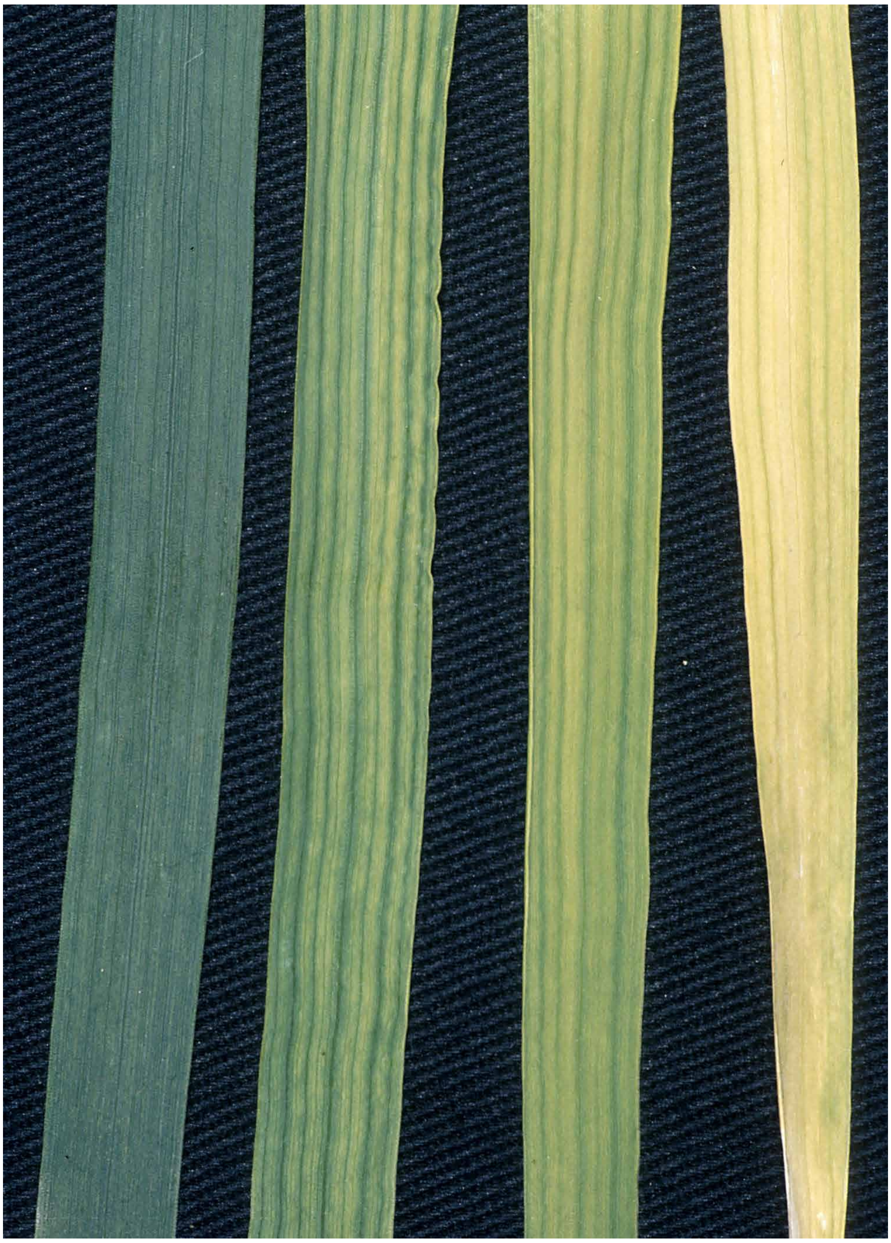

Photo 12: *Pale yellow, iron-deficient leaves, most showing prominent green veins (right) compared with dark green, healthy leaf (left).*

Source: Department of Agriculture and Food Western Australia

What else could it be?

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

Managing iron deficiency:

- No yield responses to Fe to justify soil application.
- Where symptoms occur, particularly in cold and wet conditions, they are frequently eliminated by increased soil and air temperatures.
- Foliar sprays will remove the symptoms where they occur in highly calcareous or limed soils. [51]

5.9.3 Copper

Copper (Cu) is necessary for carbohydrate and N metabolism. Inadequate Cu results in stunting. Copper is also required for lignin synthesis which is needed for cell wall strength and prevention of wilting. Deficiency symptoms of Cu are dieback of stems, yellowing of leaves, stunted growth and pale green leaves that wither easily. Deficiencies of Cu are mainly reported in sandy soils low in organic matter. Copper uptake decreases as soil pH increases. Increased P and Fe availability in soils decreases Cu uptake by plants. Rye is efficient at taking up available Cu from the soil. [52]

Deficiency symptoms

Paddock:

- Before head emergence, deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green healthy crop (Photo 13).
- After head emergence, mildly affected areas have disorganised, wavy heads. Severe patches have white heads and discoloured late-maturing plants.
- Symptoms are often worse on sandy or gravelly soils, where root-pruning herbicides have been applied, and on recently limed paddocks.

Plant:

- Youngest growth is affected first.
- First sign of Cu deficiency before flowering is growing point death and tip withering, and/or bleaching and twisting up to half the length of young leaves (Photo 14).
- Base of the leaf can remain green.
- Old leaves remain green, but paler than normal.
- Tiller production may increase but die prematurely.
- Mature plants are dull grey-black in colour with white or stained empty or 'rat-tail' heads.
- Grain in less severely affected plants may be shrivelled. Heads with full grain droop due to weak stems.

51 DAFWA (2015) Diagnosing iron deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1991

52 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press, https://www.crcpress.com/Rye-Genetics-Breeding-and-Cultivation/Schlegel/p/book/9781466561434

Photo 13: *Copper-deficient plants have pale necrotic flag leaves at head emergence.*

Source: Department of Agriculture and Food Western Australia

Photo 14: *A copper-deficient plant showing a partly sterile head and twisted flag leaf.*

Source: Department of Agriculture and Food Western Australia

What else could it be?

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

Managing copper deficiency:

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

- Mixing Cu throughout the topsoil improves availability due to more uniform nutrient distribution.
- As Cu is immobile in the soil, topdressing is ineffective, only being available to the plant when the topsoil is wet.
- In long-term, no-till paddocks frequent small applications of Cu via drilled or in-furrow application reduces the risk of plant roots not being able to obtain the nutrient in dry seasons.
- Copper drilled deep increases the chances of roots being able to obtain enough Cu when the topsoil is dry.
- Copper seed treatment is insufficient to for plant requirements in the current season. [53]

5.9.4 Manganese

Rye has been found to be tolerant of manganese (Mn) deficiency in soils in South Australia, where it produced 100% relative grain yields, and did not respond to Mn fertiliser. It was therefore regarded as Mn-efficient. [54]

Deficiency symptoms

Paddock:

- Manganese deficiency often appears as patches of pale, floppy plants in an otherwise green healthy crop (Photo 15).

Plant:

- Frequently, plants are stunted and occur in distinct patches.
- Initially, middle leaves are affected, but it can be difficult to determine which leaves are most affected because symptoms rapidly spread to other leaves and the growing point (Photo 16).
- 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.

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

54 RD Graham, WJ Davies, DBH Sparrow, JS Ascher (1983). Tolerance of barley and other cereals to manganese-deficient calcareous soils of South Australia. In Genetic aspects of plant nutrition, pp. 339–345, Springer, https://link.springer.com/chapter/10.1007/978-94-009-6836-3_40

Photo 15: *Manganese-deficient plants showing as patches of pale floppy plants in otherwise healthy crop.*

Source: Department of Agriculture and Food Western Australia

Photo 16: *Middle leaves are affected first by manganese deficiency, showing as yellowing and necrosis.*

Source: Department of Agriculture and Food Western Australia

What else could it be?

Condition	Similarities	Differences
Zinc deficiency	Pale plants with interveinal chlorosis and kinked leaves	Differences include linear tramline necrosis on Zn-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

Managing manganese deficiency:

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

- Seed Mn coating treatments have little effect in correcting the deficiency. [55]

5.9.5 Aluminium

The ability of crops to overcome aluminium (Al) toxicity varies among species and cultivars. Among the wheat family, rye is considered the most Al-tolerant species. For example, when three cereal ryes, three durum wheats and 30 triticales were sown in a gravel bed with solutions containing 0, 5, 10, 15, 20 and 40 Al µg/g, the cereal ryes tested were found to be very tolerant of Al. [56]

IN FOCUS

Aluminium long-term stress differently affects photosynthesis in rye genotypes

Two rye genotypes differing in Al tolerance (sensitive and tolerant) were exposed to 1.11 and 1.85 mM Al over three weeks. Growth, water status and photosynthesis-related parameters were assessed. After three weeks of Al exposure, both genotypes presented similar decrease in leaf growth. Al-induced relative water content decreased in both genotypes, but was more pronounced in the Al-sensitive cultivar. Aluminium toxicity induced a decrease in net photosynthetic rate only after three weeks of exposure. RuBisCo is an enzyme involved in the first major step of carbon fixation, a process by which atmospheric carbon dioxide is converted by plants and other photosynthetic organisms to energy-rich molecules. For both Al concentration conditions, RuBisCo activity decreased, however, this decrease did not limit glucose accumulation in either of the rye cultivars. This study revealed that Al-induced damages earlier in the growth of the Al-sensitive cultivar, but both genotypes showed long term high susceptibility to Al. Furthermore, the photosynthetic parameters proved to be a good tool to monitor Al-sensitivity and long term exposure showed to be crucial to evaluating Al-sensitivity. [57]

5.10 Nutritional deficiencies

To help identify nutritional deficiencies, see the GRDC's Winter cereal nutrition: the ute guide.

Making use of the crop nutrition information available

As part of the GRDC More Profit from Crop Nutrition (MPCN) extension and training for the southern region project (BWD00021), Birchip Cropping Group (BCG), in conjunction with other grower groups, has been hosting nutrition events across the southern region since 2012.

Many key nutrition areas are being investigated through the MPCN initiative; however, a few immediate resources are available to advisers to help with understanding nutrition and giving such advice.

55 DAFWA (2015) Diagnosing manganese deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-wheat

56 B Scott (1981) Species and varieties for acid soils. Riverina Outlook Conference, http://www.regional.org.au/au/roc/1981/roc198161.htm

57 S Silva, G Pinto, MC Dias, CM Correia, J Moutinho-Pereira, O Pinto-Carnide, C Santos (2012) Aluminium long-term stress differently affects photosynthesis in rye genotypes. *Plant Physiology and Biochemistry* 54, 105–112, https://www.ncbi.nlm.nih.gov/pubmed/22391128

Useful resources:

- eXtension Aus Crop Nutrition: Connecting the lab and the paddock in crop nutrition. This is a group of leading experts in crop nutrition for the Australian grains industry collaborating to provide timely, concise information on crop nutrition issues in Australia. Provides updates on the latest research and articles focusing on strategic management of crop nutrition in the current season.
- Better Fertiliser Decisions for Cropping (BFDC): Fertiliser decisions made by grain growers should all start with, and rely on, knowledge of the fertility status of paddocks. These decisions need to account for the nutrient requirements of plants for growth, nutrient availability in soils, and nutrient losses that can occur during crop growth (e.g. de-nitrification or erosion). BFDC provides the fertiliser industry, agency staff and agribusiness advisors with knowledge and resources to improve nutrient recommendations for optimising crop production. BFDC is recognised by the Fertiliser Industry Federation of Australia as the best available data for supporting the decision tools that fertiliser industry members use to formulate recommendations. [58]

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