WESTERN
JUNE 2018

GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

DURUM

SECTION 4

NUTRITION AND FERTILISER

OVERVIEW | WESTERN AUSTRALIAN SOILS | NUTRIENT MOVEMENT | NITROGEN | PHOSPHORUS | POTASSIUM | SULFUR | MICRONUTRIENTS

MORE INFORMATION

GRDC-DPIRD MySoil https://agric.wa.gov.au/n/638

GRDC 'Managing Soil Organic Matter: A Practical Guide': https://grdc.com.au/resources-and-publications/all-publications/publications/2013/07/grdc-guide-managingsoilorganicmatter

DPIRD 'Diagnosing Nitrogen Deficiency in Wheat': https://agric.wa.gov.au/n/1995

DPIRD 'Diagnosing Phosphorus Deficiency in Wheat': https://agric.wa.gov.au/n/1996

Nutrition and fertiliser

4.1 Overview

The bulk of Western Australia's soils are sandy in nature, with typically lower nutrient and water holding capacity than in other grain growing regions of Australia. These soils require addition of nutrients such as nitrogen (N) and phosphorus (P) because of their low natural fertility.

Balancing the supply of fertiliser with the nutrients removed by high-yielding crops is a constant challenge.

Water, nutrients and soil acidity (measured in pH) need careful management to maintain optimum growth conditions.

Crop N requirements depend on expected yield and protein, particularly for durum wheat.

The amount of fertiliser N required to supplement N mineralisation from the soil and the timing of its application needs to match the stage of greatest N demand from the crop.

Trace element deficiencies can be corrected with fertilisers containing micronutrients or through foliar applications.

4.2 Western Australian soils

Most WA cropping soils are ancient and were formed from granitic parent rock. Weathering over geological time has leached minerals and clay from the topsoils, leaving these chemically infertile and prone to nutrient leaching and rapid acidification.

Many WA soil profiles are duplex, consisting of a thin sandy or loamy topsoil overlaying a thicker clay layer. The sandy topsoils have a weak structure and are prone to compaction and a low water and nutrient holding capacity.

The clay subsoil can store large amounts of water, but poor structure and small pore size distribution can make it difficult for crop roots to access this moisture. WA also has large areas of deep, sandy soils.

The positive aspect of low-fertility soils is that crop nutrient supply and timing is almost entirely in the hands of the grower.

4.2.1 Organic soil components

Organic matter makes up about 2-10 percent of the soil mass and has a critical role in the physical, chemical and biological function of agricultural soils.[1]

It contributes to nutrient turnover and cation exchange capacity, soil structure, moisture retention and availability and soil buffering.

Soil organic matter is difficult to measure directly, so laboratories tend to measure and report soil organic carbon (SOC) levels, which make up about 58 percent of soil organic matter.[2]

1 GRDC, Managing Soil Organic Matter: A Practical Guide, (2013), https://grdc.com.au/resources-and-publications/all-publications/publications/2013/07/grdc-guide-managingsoilorganicmatter

2 GRDC, Managing Soil Organic Matter: A Practical Guide, (2013), https://grdc.com.au/resources-and-publications/all-publications/publications/2013/07/grdc-guide-managingsoilorganicmatter

Globally, SOC is typically between 0.5 and 4 percent in dryland agricultural topsoils, with the highest amounts in cool, moist environments that have clay-rich soils and the lowest levels in warm, dry environments with sandy soils such as WA[3].

The SOC content in WA cropping soils typically ranges from 0.8 to 2 percent in surface (0-10 centimetre) layers – or the equivalent of 8-20 tonnes of carbon per hectare (t C/ha) – assuming a bulk density of 1.0 grams per cubic centimetre. This is among the lowest of agricultural soils anywhere in the world.[4]

There is typically a fixed ratio of carbon (C), N, P and sulphur (S) in soil organic matter. Each tonne of C is associated with about 80 kilograms of N, 20 kg of P and 14 kg of S.[5]

When soil organic matter is broken down, these amounts of nutrients are potentially available to crops.

Managed optimally, WA's continuous cropping systems that predominantly produce wheat are likely either to just maintain – or lose – SOC.

4.2.2 Soil test critical values

Tests of the top 10 cm of soil are the best way to estimate the status of potassium (K), P and S.

Nitrogen status is better estimated with models, deep soil nitrate tests and plant tissue tests. Micronutrient status is best measured from plant tests.

The critical value of a soil test is the value required to achieve 90 percent of crop yield potential.

The range around the critical value represents the reliability of the test. The narrower the range, the more reliable the data, as highlighted in Table 1.

Table 1: Critical soil test values at two soil-testing depths for phosphorus, potassium and sulphur according to WA soil types.[6]

Soil sampling depth (cm)	Nutrient*	Soil type	Critical value (mg/kg)	Critical range (mg/kg)
0-10	Phosphorus	Grey sands	10	10-16
		Other soils	23	22-24
	Potassium	All	41	39-45
		Yellow sands	44	34-57
		Loams	49	45-52
		Duplexes	41	37-44
	Sulfur	All	4.5	3.5-5.9
0-30	Phosphorus	All	11	10-11
	Potassium	All	N/A	N/A
	Sulfur	All	4.6	4.0-5.3

*Micronutrient status is more reliably measured using plant tissue rather than soil testing (see micronutrient section below).

Nitrogen soil tests are a poor indicator of nitrogen requirements and need to be used in conjunction with potential yield outlooks (see nitrogen section below).

If a soil test value is less than the lower critical value limit, wheat yield is likely to respond to a nutrient application, as shown in Figure 1. Soil test critical values do not predict optimum fertiliser rates.

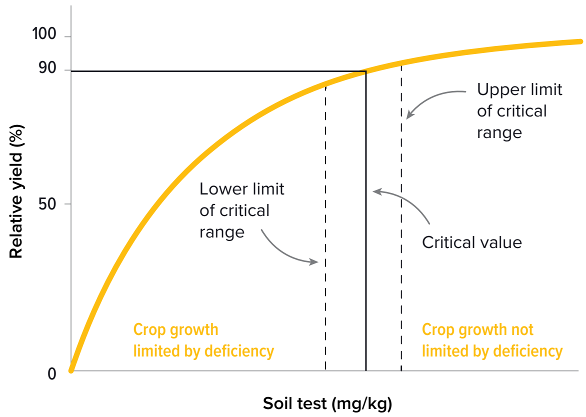
3 DPIRD, Soil Organic Matter hub, 2017, https://www.agric.wa.gov.au/soil-carbon/soil-organic-matter-frequently-asked-questions-faqs

4 DPIRD, Soil Organic Matter hub, 2017, https://www.agric.wa.gov.au/soil-carbon/soil-organic-matter-frequently-asked-questions-faqs

5 DPIRD, Soil Organic Matter hub, 2017, https://www.agric.wa.gov.au/soil-carbon/soil-organic-matter-frequently-asked-questions-faqs

6 Anderson, G, Chen, W, Bell, R, Brennan, R (2016) Critical values for soil P, K and S for near maximum wheat, canola and lupin production in WA: www.giwa.org.au

Figure 1: *A generalised soil test-crop response relationship defining the relationship between soil test value and percent grain yield expected. A critical value and critical range are defined from this relationship. The relative yield is the unfertilised yield divided by maximum yield, expressed as a percentage. Typically 90 percent of maximum yield is used to define the critical value but critical values and ranges at 80 percent and 95 percent of maximum yield can also be produced.*[7]



To determine how much fertiliser to apply, soil test results need to be considered in combination with information about potential crop yield, soil type, gross margin analysis and nutrient removal in previous seasons.

4.3 Nutrient movement

Nutrients arrive at the wheat root by the processes of mass flow, root interception and diffusion.

Mass flow occurs when soluble and mobile nutrients are swept along in the flow of water moving from the soil towards the wheat root in the transpiration stream.

The nutrients that tend to be taken up in mass flow are nitrate (NO_3^-), calcium (Ca), magnesium (Mg) and sulphate (SO_4^{2-}) and these soluble nutrients are the most susceptible to leaching. About 80 percent of nitrate-N reaches wheat roots in this way.[8]

Research and experience in WA indicates splitting N applications can reduce leaching risk and help to maintain high concentrations of nitrate-N in the soil solution during periods of rapid crop growth.

Less soluble nutrients move to plant roots along a concentration gradient by a process called diffusion. Nutrients move from an area of high concentration (the bulk soil solution) towards an area of lower concentration (the root surface).

About 90 percent of P and 80 percent of K taken up by wheat is typically via diffusion.[9] Banding K and P fertilisers can promote high nutrient concentrations in the active root zone.

Root interception is responsible for less nutrient uptake. For example, just 1-2 percent of the uptake of N, P and K is due to interception by roots as these grow through the soil.

Immobile nutrients, such as zinc (Zn) and P are taken up when intercepted by roots or arbuscular mycorrhizal fungi (AMF). The activity of AMF tends to be reduced by canola crops and high levels of P fertiliser. Additional Zn fertiliser may be needed for wheat after canola or when fertilised with high levels of P.

7 Anderson, G, Chen, W, Bell, R, Brennan, R (2016) Critical values for soil P, K and S for near maximum wheat, canola and lupin production in WA: www.giwa.org.au

8 Anderson, W.K. The Wheat Book: Principles and Practice, DAFWA, 2000, http://researchlibrary.agric.wa.gov.au/bulletins/6/

9 Anderson, W.K. The Wheat Book: Principles and Practice, DAFWA, 2000, http://researchlibrary.agric.wa.gov.au/bulletins/6/

4.4 Nitrogen

Figure 2: *Growers are advised to consider tactical application of N fertiliser in response to expected crop requirements, seasonal conditions and commodity and fertiliser prices.*

(SOURCE: GRDC)

Nitrogen supply should be matched to crop requirements, which may vary as the season progresses – particularly as WA's sandy soils are prone to N leaching. Growers are advised to consider tactical application of N fertiliser in response to expected crop requirements, seasonal conditions and commodity and fertiliser prices.

Crop N requirements are related to grain yield, which in turn is driven by rainfall, crop density, root disease, weeds and the status of other nutrients.

Most N in the soil profile is in an organic form that must be mineralised before becoming available for crop uptake.

The goal of N management is to supplement mineralised soil N with fertiliser N to match crop requirements.

Tools and models, such as Yield Prophet®, NULogic and N Broadacre, can estimate N supply from the various pools available and be used to calculate N fertiliser requirements as the season progresses. See section 4.47 for more detail.

Soil testing prior to sowing is key to developing an effective N budget for durum wheat crops during the growing season.

When conducting soil tests, it is important to test for N to the depth of anticipated crop root growth.

Applications of N at sowing, or up to the start of stem elongation, significantly contribute to crop biomass and grain yield response.

Later applications of N, from booting to flowering, tend to facilitate greater grain protein responses.

Pasta manufacturers prefer durum wheat with 13 percent grain protein and growers can use late-season, topdressed N to help meet this target.

When applying N, yield will typically increase to a maximum point, whereas grain protein levels may continue to increase beyond this level with further applications.

In high yielding situations and in favourable conditions, grain protein levels in many new durum varieties may still fall below 13 percent.

Applications of N at sowing, or up to the start of stem elongation, contribute more to wheat crop biomass and grain yield response than later applications of N, which tend to facilitate greater protein responses.

4.4.1 Nitrogen triggers tillers

The number of tillers for a particular variety provides a good indication of crop N status. For example, in a typical crop, the first tiller emerges from the base of leaf-one at the same time that leaf-three emerges on the main stem. Absence of this tiller is a symptom of N deficiency if other inputs are adequate.

Nitrogen demand then increases significantly during stem elongation – a period of rapid leaf area expansion and crop growth.

Nitrogen taken up during stem elongation helps build crop yield by increasing head and grain numbers and provides N reserves for grain protein.

There is a direct relationship between N supply (from all sources), grain yield and grain protein content.

Soil N status and potential yield dictate a paddock's N supply zone – whether it is deficient, moderate or excessive – as outlined below:

- **Zone 1:** Extreme N deficiency
  When N supply is deficient, adding N will increase grain yields markedly. But it is likely grain protein levels will remain unchanged, or even decline slightly, with additional N. Crop yield is only half, or less, of potential and cereal protein levels will be as low as 7-8 percent.[10]
- **Zone 2:** Moderate N supply
  As N supply increases to moderate levels, both crop yield and grain protein increase with additional N fertiliser. Crop yields are 60-80 percent of potential but grain protein is still below 10 percent. In general, returns on applied N are maximised at grain protein levels between 10-11 percent. Fertiliser strategies to produce grain protein levels above this range need to be calculated against the profitability of supplying durum wheat to market at 13 percent protein.[11]
- **Zone 3:** Excessive N supply
  Nitrogen supply in excess of crop yield potential can cause yield decline, high screenings and low test weight – even while grain protein continues to increase. For example, grain protein levels of 14 percent can result in a drop in grain yield of about 10 percent. In general, the efficiency of N conversion to grain decreases as N supply increases.

  Grain protein levels above 10-11 percent usually indicate excess N has been applied because yield and protein payments for durum wheat will offset the extra cost of the N.

  Conversely, if grain protein levels are consistently below 10-11 percent – provided other inputs and management are satisfactory – it is likely the N strategy is forgoing yield potential and could be adjusted upwards.[12]

4.4.2 Nitrogen pools

Wheat crops access N from three main soil pools. The first is stable organic N (SON), which is:

- The biggest source of soil N
- Released as microbes break down organic matter (mineralise)

10 Anderson, W.K. The Wheat Book: Principles and Practice, DAFWA, 2000, http://researchlibrary.agric.wa.gov.au/bulletins/6/

11 Anderson, W.K. The Wheat Book: Principles and Practice, DAFWA, 2000, http://researchlibrary.agric.wa.gov.au/bulletins/6/

12 Anderson, W.K. The Wheat Book: Principles and Practice, DAFWA, 2000, http://researchlibrary.agric.wa.gov.au/bulletins/6/

- Provided to plants in a form of ammonium (NH_4^+) and NO_3^-
- Mineralised most rapidly when the soil is moist and warm
- Increased with cultivation
- Reduced with incorporation of residues that contain a high ratio of C to N, as this causes N immobilisation (the opposite of mineralisation).

During a typical season, about 2 percent of the SON pool becomes available to crops. With significant rain in summer and autumn, mineralisation can be as high as 3 percent.[13]

SON is estimated by measuring organic carbon percentage (OC%) in the profile.

A continuously cropped loamy soil with an OC% of 1 percent can supply as much as 48 kg/ha of N (the equivalent of 1 t/ha of grain yield) from the SON pool.

Residue organic N (RON) is another pool for plants to access.

This is significant when wheat crops follow grain legumes, such as lupins, field peas, chickpeas and faba beans, or legume-based pastures.

This source of N is mineralised rapidly to NH_4^+ and then NO_3^- before and during the growing season.

RON is mostly depleted within two or three years of the legume phase, as shown in Table 2.

Table 2: Approximate quantity of legume nitrogen available to a wheat crop in the years following the legume rotation.[14]

	Legume nitrogen supplied to wheat in the years after legume rotation (kgN/ha)				
Legume crop/pasture yield	Year 1	Year 2	Year 3	Year 4	Total
1t/ha legume crop	16	7	4	2	29
2t/ha legume crop	30	15	7	4	56
4t/ha pasture (80% legume content)	23	11	4	3	42

*Soil type: loamy sand. Legume crop harvest index: medium.

Fertiliser N is required when SON and RON sources are insufficient to supply crop requirements.

This is typically in the forms of urea, NH_4^+ and NO_3^-.

Urea rapidly changes to NH_4^+, which in turn changes to NO_3^- and both reactions are more rapid when the soil is warm and moist.

Residual mineral N can be available from mineralisation or fertiliser applied in previous years, particularly from low-yielding crops.

Residual mineral N is measured by soil testing down the profile, for example to a depth of 60 cm.

In years following leaching rain, it is recommended to undertake deeper soil testing to get a good indication of this pool.

4.4.3 Wheat uptake of nitrogen

Wheat takes up both NH_4^+ and NO_3^- by its roots. Ammonium is an intermediate product in the mineralisation of organic matter to NO_3^- and is immobile in the soil due to its positive electric charge. It is usually found in the topsoil and at lower concentrations than NO_3^-.

13 GRDC Western Wheat GrowNotes™, www.grdc.com.au/grownotes

14 Quinlan, R (2012) Planfarm, How to get more nitrogen from pasture legumes delivered to crops, www.giwa.org.au/

The negative charge of nitrate gives it the ability to move in solution to the plant roots and to leach into the subsoil – and sometimes below the root zone after heavy rain.

When small amounts of NH_4^+ and NO_3^- are taken up by the crop, these are quickly converted to amino acids and then proteins.

When a large amount of NO_3^- is taken up by a vegetative crop, it remains as NO_3^- in the plant for several weeks.

The NO_3^- content of young plants is a good indication of the short-term supply of N. Nitrate is not typically found in the crop after stem elongation.

Applying urea makes the topsoil alkaline in the short term. Plant uptake of NH_4^+ formed from the urea reverses this reaction when roots excrete a hydrogen ion (proton H+) in exchange for the NH_4^+.

The process of nitrification, converting NH_4^+ to NO_3^-, also tends to acidify the topsoil.

Crop uptake of NO_3^- makes the soil more alkaline because roots exchange a hydroxyl ion (OH^-) for nitrate.

Production of NO_3^- has the effect of making the topsoil more acidic and, if it is then leached, the subsoil becomes more alkaline when NO_3^- is taken up by roots.

The upshot of these reactions is that N supplied to crops, whether from fertiliser or legume N fixation, can lead to topsoil acidification, which can be managed/neutralised by liming.

4.4.4 Nitrogen use efficiency

Figure 3: *Fertiliser nitrogen, such as urea, is required when soil N is insufficient to supply crop requirements.*

(SOURCE: GRDC)

Nitrogen use efficiency (NUE) is a measure of how well N is retrieved by the crop from the soil profile and converted into grain. Wheat crop management practices that can help to increase NUE include:

» Sowing early or into dry soil – ensures roots keep up with N being leached down the profile by the wetting front

» Minimising incidence of root disease – break crops or applied seed fungicides

» Ensuring yield is not limited by deficiencies of other nutrients

- » Correcting acidity by liming – optimises root growth
- » Reducing risks of take-all disease using a break crop
- » Correcting soil compaction to increase the speed of root growth down the profile – potentially using deep ripping to promote root growth
- » Cautiously using chlorsulfuron, triasulfuron and trifluralin herbicides that can prune crop roots and reduce NUE
- » Banding N below or beside the rows rather than topdressing.

4.4.5 Nitrogen for protein response

A key risk for durum wheat growers is applying too much N, too early in the season. An over-supply of N prior to stem elongation can result in increased crop biomass, more water use and a tendency for durum wheat to set an unattainable yield potential (more grains per square metre).[15]

Durum wheat will reach yield potential when protein levels are between 10.5-11 percent.[16]

It is often difficult to get N requirements exact at the beginning of the season, but soils with available N of more than 50 kg/ha will typically sustain durum wheat crops until stem elongation.

This level of N is typically best applied early in the crop's development and then more N applied later to boost protein to the 13 percent required, as highlighted in Table 3.

Table 3: Comparison of grain protein (%) across different nitrogen application timings*[17]

Nitrogen treatment	Tamaroi	Caparoi⚪	Saintly⚪	Tjilkuri⚪	Hyperno⚪	Yawa⚪
Nil	11.9	11.9	11.9	11.6	11.3	11.4
80 kg N/ha @ GS30**	13.1	13.1	12.9	12.9	12.4	12.5
40 kg N/ha @ GS30** and 40 kg N/ha @ GS47**	13.2	13.4	13.2	13.2	12.5	11.9
80 kg N/ha @ GS47**	13.3	13.4	13.0	13.0	12.4	12.3
LSD (5%)	0.2%					

* Results expressed as a percentage of dry basis (db) and averaged across three years of trial work at Paskeville from 2009 to 2011. The shaded treatments achieved premium grade classification based on protein for DR1.
** GS30 (onset of stem elongation), GS47 (flag leaf emergence)

4.4.6 Nitrogen timing and late season topdressing

Grain protein can be increased and grain size maintained when N application is appropriately timed.

Topdressing durum wheat from booting stage to mid-flowering has been shown to be the most effective time to increase protein and minimise the risk of high grain screenings.[18]

As a general rule-of-thumb, to increase grain protein by 1 percent, it is advised to apply 6-8 kg/ha of N for every 1 t/ha of yield potential on many soil types[19].

For example, a crop with 4 t/ha yield potential will need an extra 24-32 kg/ha of N applied after stem elongation to increase grain protein by one percent.

But late season application is not always easy because rain after application is needed to move N into the root zone and minimise volatilisation losses.

15 GRDC (2014) Fact Sheet 'Durum Quality and Agronomy — Southern Region', GRDC, www.grdc.com.au/GRDC-FS-Durum
16 GRDC (2014) Fact Sheet 'Durum Quality and Agronomy — Southern Region', GRDC, www.grdc.com.au/GRDC-FS-Durum
17 GRDC (2014) Fact Sheet 'Durum Quality and Agronomy — Southern Region', GRDC, www.grdc.com.au/GRDC-FS-Durum
18 GRDC (2014) Fact Sheet 'Durum Quality and Agronomy — Southern Region', GRDC, www.grdc.com.au/GRDC-FS-Durum
19 GRDC (2014) Fact Sheet 'Durum Quality and Agronomy — Southern Region', GRDC, www.grdc.com.au/GRDC-FS-Durum

In more marginal durum wheat growing areas, it may be better to target an earlier application of N.

In higher rainfall areas with good subsoil moisture and a strong chance of follow-up rain, applications at early flowering stage may have more success.

Applying N at strategic times throughout the season to match crop demand and soil moisture supply can increase durum wheat yield and water use efficiency above that of a single application at sowing, as highlighted in Table 4.

Table 4: Grain yield response and water use efficiency of 100 kg/ha nitrogen applied either at sowing or at various growth stages throughout the season.[20]

Nitrogen treatment	Grain yield (t/ha)	Water use efficiency
Nil	2.25	7.1
Sowing	2.86	9.1
3.5 leaf	3.00	9.5
1st node	3.02	9.6
3.5 leaf + 1st node	3.17	10.1
3.5 leaf + awn peep	3.05	9.7
1st node + awn peep	2.96	9.4
Sowing + 3.5 leaf + awn peep	2.95	9.4
$LSW_{0.05}$	0.14	

Mineralised soil N can be a major source of crop N and in some seasons little if any fertiliser N will be required to meet wheat yield potential.

Crop requirements for fertiliser N are a function of demand (yield potential) and supply (soil N supply).

The goal is to put on enough early N to achieve a low or average yield and then monitor conditions as the season unfolds, adding more N at early stem elongation (Zadoks Growth Scale stage GS31-33) if yield potential (demand) requires it.

In higher rainfall areas, if the season continues to progress well above average, further N can be added a few weeks later.

In most southern WA areas, cereal stem elongation (stages GS31-GS33) is the best time for later N application, which typically occurs sometime in July — depending on season and sowing date.

Using moderate N rates early in the season enables a low to average yield potential to be established, without compromising the prospect of higher yields if spring conditions are favourable.

A deferred approach to N also limits the amount of N that is put at risk of loss from denitrification (waterlogging) or leaching.

As shown in Figures 4 and 5, there is increased demand for N as yield potential increases.

20 GRDC (2014) Fact Sheet 'Durum Quality and Agronomy — Southern Region', GRDC, www.grdc.com.au/GRDC-FS-Durum

Figure 4: *Relationship between nitrogen requirement and grain yield for increasing yield potential in a high rainfall area (with 50 kg/ha mineralised N).*[21]

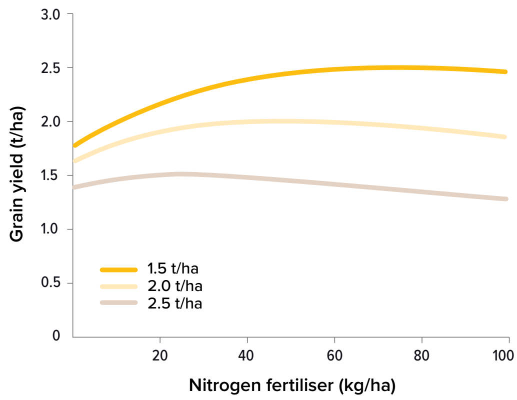
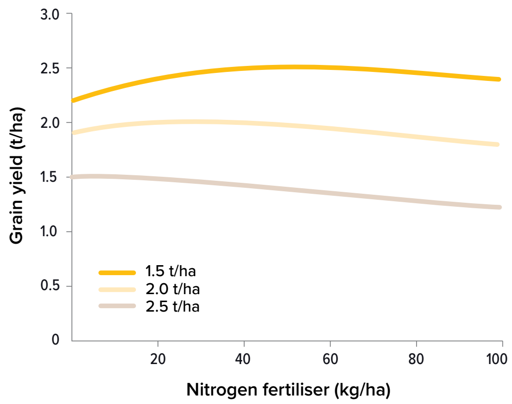


Figure 5: *Relationship between nitrogen requirement and grain yield for increasing yield potential in a low rainfall area (with 70 kg/ha mineralised N).*[22]



These Figures are outputs from the decision support tool 'Select Your Nitrogen' (SYN), developed by the Department of Primary Industries and Regional Development (DPIRD) with Grains Research and Development Corporation (GRDC) funding.

The assumption for the high rainfall example is a dry start to the season (no NO_3^- leaching) and a wheat-legume-wheat rotation delivering about 50 kg of mineralised N/ha.

For the low rainfall example, the assumption is a wheat-fallow-fallow rotation (two years of drought) delivering 70 kg of mineralised N/ha.

4.4.7 Late nitrogen top-ups

The impact of late-applied N on grain yield and protein depends on the wheat growth stage at which the N is applied, previous N history and soil moisture status.

Later applications of N can increase tiller survival and longevity of green leaf area (season permitting) and can also contribute to yield through larger grains or, depending on time of application, more grains per ear.

Nitrogen taken up after flowering is more likely to increase grain protein and less likely to increase grain numbers or grain size.

21 DPIRD 'Select Your Nitrogen' model, http://www.climatekelpie.com.au/manage-climate/decision-support-tools-for-managing-climate/syn-select-your-nitrogen

22 DPIRD 'Select Your Nitrogen' model, http://www.climatekelpie.com.au/manage-climate/decision-support-tools-for-managing-climate/syn-select-your-nitrogen

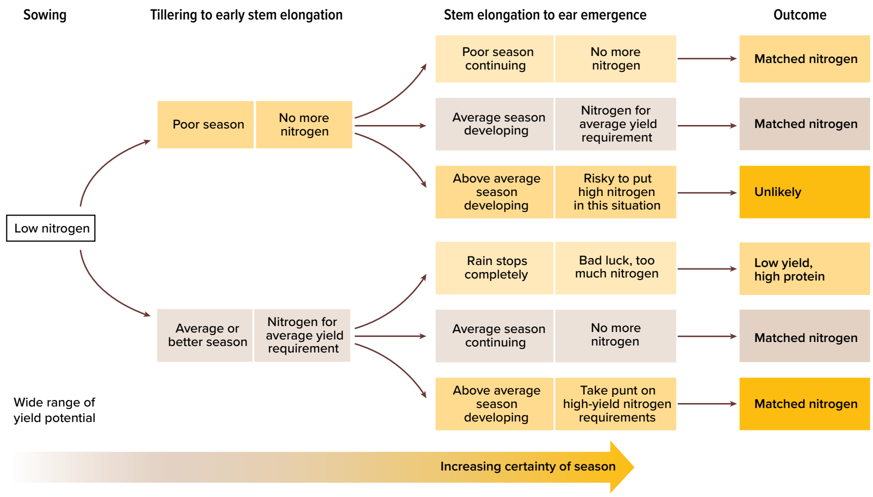
Decision support tools, such as N Broadacre, NUlogic and Yield Prophet®, can be used to explore the economics of late-season N use strategies for a range of seasonal outlooks.

Applying late N in anticipation of a follow-up rain is risky because if the season end does not deliver sufficient rain, yield can decline due to 'haying-off'.

But if N is applied after a rain that exceeds about 20 millimetres across two days, this can result in significant yield increases.[23]

During the period from stem elongation to ear emergence (stages GS30 to 39), a further assessment of crop N requirements can be made according to the season outlook, as shown in Figure 6.

Figure 6: *Decision tree for in-season nitrogen applications according to the progress of the season and crop developmental stages.*[24]



Later applications of N can increase tiller survival and longevity of green leaf area (where the season permits) and can contribute to yield.

But, when the season ends more abruptly, later N (in excess of yield potential) can cause increases in grain protein at the expense of yield.

Late season N applications are typically only warranted for wheat crops in high rainfall areas — although rainfall amount and pattern in some seasons in lower and medium rainfall areas can also deliver yield responses to late season N.[25]

Even in a season tracking above average, the recommendations for in-season N application can still be observed. There should be enough soil moisture and a reasonable prospect of follow-up rain to convert the applied N into yield.

4.4.8 Premiums for protein

Premiums available in the market for protein can influence the decision to apply N late in the season for durum wheat crops.

The protein percentage must exceed 13 percent in durum wheat to reach DR1 classification and optimise grain returns.

High protein wheat is more likely to be produced in the northern and eastern WA grainbelt on heavy soil types.

23 GRDC (2014) Fact Sheet 'Durum Quality and Agronomy — Southern Region', GRDC, www.grdc.com.au/GRDC-FS-Durum

24 Palta, J, Bowden, W, and Asseng, S (2003) Timing of late applications of N fertiliser and season on grain yield and protein in wheat, CSIRO and DAFWA, www.regional.org.au/au/asa/2003/p/5/palta.htm

25 Palta, J, Bowden, W, and Asseng, S (2003) Timing of late applications of N fertiliser and season on grain yield and protein in wheat, CSIRO and DAFWA, www.regional.org.au/au/asa/2003/p/5/palta.htm

However, fertiliser and application costs will be critical to chasing protein premiums from late N applications.

For example, if the N costs $20/ha and application costs $10/ha, the premium must be at least $15/t to break even at a yield of 2 t/ha.

4.4.9 Matching nitrogen to yield potential

Crop yield potential is the major driver of N requirements in durum wheat. Yield forecasting is crucial to optimising N rates in all wheat crops.

Most of the N decision support models outlined in this chapter incorporate various methods of estimating crop yield potential.

Wheat crops typically require about 40-45 kg/ha of N for every 1 t of grain produced. Nitrogen losses due to poor root growth, NO_3^- leaching or volatilisation into the atmosphere need to be accounted for and added to this figure.

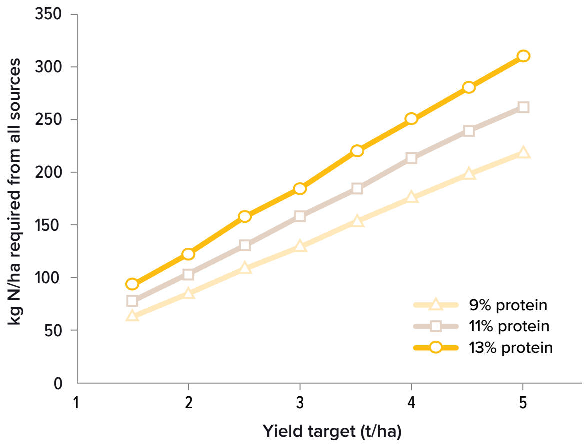
These losses are considered in the common rule-of-thumb estimate that half of soil and fertiliser N is taken up by the crop.

Light soils, especially in higher rainfall areas, are likely to cause crops to have lower nitrogen use efficiency (NUE) than medium and fine textured soils.

The N required from all sources (soil, legume residues and fertiliser) to achieve a grain yield at a range of protein levels is illustrated in Figure 7, which shows an increasing amount of N is required to achieve higher protein as yield increases.

The goal is to determine the value of the extra yield and protein relative to the fertiliser costs of achieving it.[26]

Figure 7: *The amount of nitrogen required from all sources (soil, legume residues and fertiliser) to achieve a grain yield at a range of protein levels (derived from the Nitrogen Calculator).*[27]



4.4.10 Decision support tools for calculating crop nitrogen requirements

Due to many processes involved in delivering N to the wheat crop, models can be used to estimate crop requirements, soil supply and, therefore, the fertiliser N required to reach yield potential.

26 GRDC (2014) Fact Sheet 'Durum Quality and Agronomy — Southern Region', GRDC, www.grdc.com.au/GRDC-FS-Durum

27 Palta, J, Bowden, W, and Asseng, S (2003) Timing of late applications of N fertiliser and season on grain yield and protein in wheat, CSIRO and DAFWA, www.regional.org.au/au/asa/2003/p/5/palta.htm

Models for calculating crop N requirements include:

N Broadacre

- A user-friendly iTunes app
- Based on the Select Your Nitrogen (SYN) model developed by DPIRD
- Incorporates expected value of the grain
- Accounts for cost of the extra N to determine economics of application.

NUlogic

- Developed by CSBP
- Available with paid and accredited access
- Can determine the yield and profit response from applied N
- Can be used to interpret soil and tissue tests.

Yield Prophet®

- Based on the Agricultural Production Simulation (APSIM) model
- Examines agronomic and economic responses to N rates and timing
- Provides a range of possible yield outcomes based on historical weather data
- Available through agronomists or directly through the Yield Prophet® website
- Requires calibration to soil type.

iPaddockYield

- An iPhone and iPad app
- Available through the iTunes app store
- Designed by a WA grain grower
- Estimates wheat yield throughout the season
- Provides a basic N requirement to match yield estimates.

GreenSeeker®

- Simpler support system based on crop reflectance methods
- Requires an N-rich strip set up at the start of season to assess N status
- Involves observation of crop response to the various strips — visually or using infrared GreenSeeker® technology
- If there is significant response to these strips, crop yields are likely to respond to topdressed N.

4.5 Phosphorus

Phosphorus (P) is important in wheat plants for growing tissue where cells are actively dividing, including at seedling root development, flowering and seed formation.

It is advised to undertake soil testing to determine the P status of a paddock.

Soil P tests are best interpreted in association with the soil's capacity to absorb or fix P, which is estimated by the phosphorus buffering index (PBI).

The higher the PBI, the more difficult it is for the plant to access P and the higher the P concentration required to optimise yields.

Phosphorus does not typically move readily in soils, except in very light sandy soils in high rainfall areas.

Soil P test critical ranges for wheat are 10-16 mg P/kg for grey sands and 22-24 mg P/kg for other soils (for a depth of 0-10 cm). But research has shown a single critical value of 11 mg P/kg is suitable for wheat on all soil types when testing to a depth of 0-30 cm.

Results from more than 100,000 soil tests indicate most WA growers are operating at or above the soil P levels required for near-maximum crop production – with 85 percent of tests returning soil P test values higher than the critical Colwell-P value (14-23 mg P/kg).[28]

Research has shown WA grain growers are, on average, applying almost twice the amount of P required and could cut applications without losing productivity or reducing soil P levels.

This has led to further analysis of the economic and agronomic benefits of diverting P fertiliser dollars into liming for soil acidity amelioration.

Some WA soils have been shown to be responsive to fertiliser P even when soil test P levels show that P is adequate. This is particularly the case for water-repellent soils where the soil surface does not wet-up evenly and the P on dry patches remains unavailable to the crop and with soils that have a high PBI.

Preliminary results suggest that when soil pH is below 5 (measured in calcium chloride, or $CaCl_2$), soil P is about 20 percent less available than when soil pH is above 6.

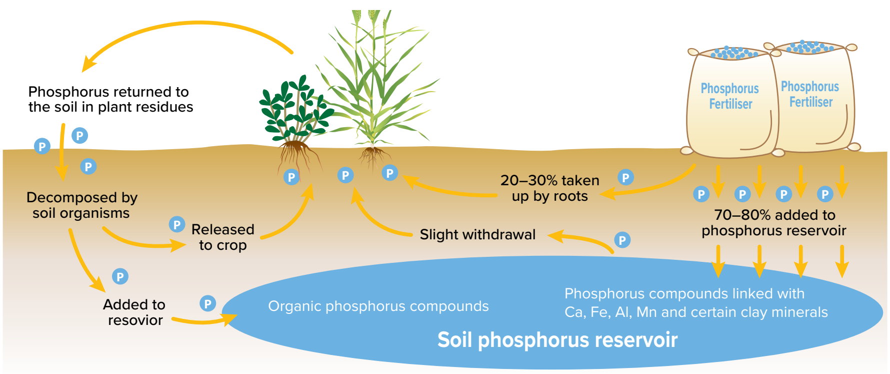
In acidic soils, aluminium (Al) is released into the soil solution, causing root pruning. This reduces the volume of soil that can be explored by the roots and the opportunity to intercept soil P, which is highly immobile in soil.

The Crop Phosphorus Model, developed by DPIRD, enables users to quantify the yield and economic response of broadacre crops to applications of P fertiliser in WA. It can be accessed via this link https://www.agric.wa.gov.au/crop-phosphorus-model.

4.5.1 Soil phosphorus

Soil P is present in soil as either undissolved P in old fertiliser granules, P that is sorbed onto soil constituents or P that is bound-up in organic matter, as shown in Figure 8.

Figure 8: *The phosphorus cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited.*[29]



Phosphorus fertiliser is typically applied in a water-soluble form that can be readily taken up by plants. But, in this form, P is not stable and rapidly reacts in the soil (principally with iron (Fe), Al and Ca) to form insoluble, more stable compounds.

28 GRDC (2016) Western Wheat GrowNotes™, Section 5.7 Pg 15 Phosphorus, GRDC, www.grdc.com.au/GrowNotes

29 GRDC (2016) Western Wheat GrowNotes™, Section 5.7 Pg 15 Phosphorus, GRDC, www.grdc.com.au/GrowNotes

This means there is strong competition for water-soluble P from the soil and from plant roots, with only 5-30 percent of the P applied typically taken up by the crop in the year of application.[30] Phosphorus is relatively immobile in soils and P applied to the 0-10 cm layer of most WA soils tends to remain in that layer, especially in no-tillage systems.

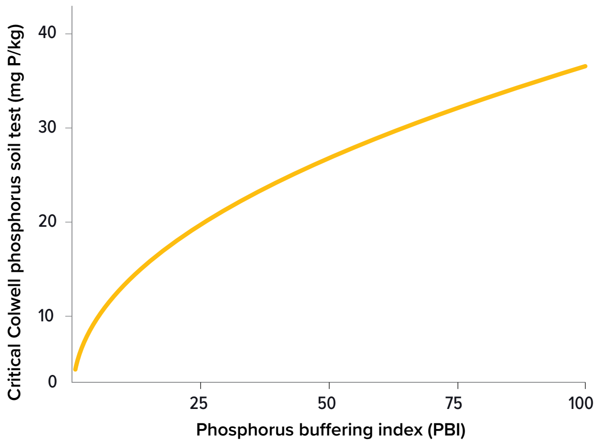
However, grey sands have low P sorption capacity and P in these soils can leach from the 0-10 cm soil layer and accumulate in layers below 10 cm.[31]

4.5.2 Soil testing for phosphorus

Determining the soil ability to fix P can underpin P fertiliser decisions.

A high P-fixing soil will require significantly more P fertiliser than a low P-fixing soil, as shown in Figure 9.

Figure 9: *Relationship between phosphorus required to meet 90 percent wheat yield potential (Critical Colwell P) and the P-fixing capacity of a soil (phosphorus buffering index).*[32]



Commercial tests have been developed to determine the P fixing capacity of soils.

Results from these tests can be used in conjunction with other soil and crop traits to optimise fertiliser P applications. Key features of P testing for P include:

- Phosphorus retention index (PRI) — direct measure of P-sorption and soil ability to fix P
- Phosphorus buffering index (PBI) — index is adjusted for pH (becoming the Australian standard for measuring soil P-sorption)
- Reactive iron test (RIT) — measures amount of iron extracted from soil as an indirect measure of soil ability to fix P
- Diffuse gradient technology phosphorus (DGT-P) — relatively new method that mimics the action of the plant roots in accessing available P.

30 GRDC (2016) Western Wheat GrowNotes™, Section 5.7 Pg 15 Phosphorus, GRDC, www.grdc.com.au/GrowNotes

31 GRDC (2016) Western Wheat GrowNotes™, Section 5.7 Pg 15 Phosphorus, GRDC, www.grdc.com.au/GrowNotes

32 Quinlan, R (2012) Planfarm, Phosphorus WA Fact Sheet, soilquality.org.au/factsheets/phosphorus

4.6 Potassium

Sandy soils in WA are prone to K deficiency. This can cause shrivelled grain and exacerbate frost and leaf disease impacts, as native and fertiliser applied K are held poorly and subject to leaching.

In most sandy soils, K concentration is highest in the surface layer where the organic matter is higher. Soil types of WA's west midlands and southern sandy soils are commonly K deficient.

Most clay and clay-loam WA soils contain sufficient K for optimum wheat and pasture production, but K deficiency is starting to show up in some duplex and loam soils.

Until the early 1990s, duplex soils rarely showed responses to K.

But responses to the application of K on these soils are now well documented in the central and southern grainbelt.

Potassium deficiency has also been identified on York gum and red loam soils near Moora.

Subsoil K can be a significant K store in some soils.

The economically optimum rate for K fertiliser will vary between paddocks and relative to yield potential, soil K test value and the fertiliser being used.

Research has found stubble contains up to three times as much K as grain — making it important to account for K export after harvest when calculating nutrient budgets.[33]

Potassium deficiency diagnosed in-crop cannot typically be corrected until the following season.

Early season K deficiency can be more detrimental to crop yield than late season deficiency.

Deficiency tends to occur initially in older leaves and can be mistaken for leaf diseases, such as yellow spot (*Pyrenophora tritici-repentis*) and Septoria nodorum blotch, or SNB (*Stagonospora nodorum blotch*).

Soil acidity, soil compaction and waterlogging modify root growth and lower the capacity of wheat to extract subsoil nutrients, including K. As a result, there is a poor relationship between soil test K (and other nutrient) values and crop yield response in wheat across all soil types.

The critical range for K across soil types in WA is 39-45 mg K/kg to achieve a relative yield of 90 percent for wheat.[34]

Loams have a higher critical range of 45-52 mg K/kg at depth.[35] In paddocks with high yield potential, profitable responses have been measured where the soil test result was up to 45 mg K/kg. Topdressing test K strips in soils above 30 mg K/kg can help determine economic responses.[36]

Windrow burning and canola swathing can concentrate K in some cases — causing big spatial variations in K content across paddocks. It is, therefore, advised to use soil K tests in conjunction with tissue testing and visual crop symptoms to determine application rates for paddocks.

However, tissue testing only determines K deficiency — not requirements — and is useful for determining K requirements for following seasons.

Potassium lost through product removal should be replaced when paddocks reach a responsive situation, as shown in Table 5.

33 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

34 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

35 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

36 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

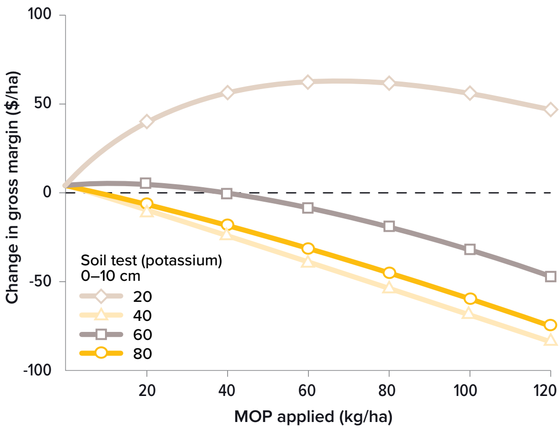
Table 5: Potassium removal per tonne of produce.[37]

Crop	Annual K removal (kg)
Wheat	4
Barley	5
Oats	5
Canola	5
Lupins	10
Oaten hay	25

The economically optimum rate of K fertiliser to apply will differ between paddocks and depend on crop yield potential, soil K test value and fertiliser being used.

Soil tests for K can be used in conjunction with the K model developed by DAFWA to determine the predicted gross margin from applying muriate of potash (MOP), as shown in Figure 10.

Figure 10: *Economic response to applying muriate of potash (at a cost of $800 per tonne) for wheat (estimated return of $240/t) with a potential yield of 2 t/ ha.*[38]



4.6.1 Potassium fertiliser placement and timing

Muriate of potash (MOP) is the cheapest form of K (with a potassium chloride (KCL) concentration of 49.5 percent K) and is typically applied by topdressing either at seeding or up to five weeks after seeding.[39]

Using MOP rates higher than 30 kg/ha sown directly with seed (at 22 cm row spacing) has been found to have potential to significantly reduce crop germination and establishment. For this reason, it is recommended K is banded away from the germinating seed.[40]

Sulphate of potash is less damaging than MOP and can be drilled directly with seed, but can be considerably more expensive per unit of K.

Banded K has been shown to be twice as accessible to crops as topdressed K, potentially because the crop is able to access this source before weeds can.

37 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

38 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

39 Quinlan, R, and Wherret, (2016) WA Potassium – Fact Sheet, Soilquality.org.au, http://www.soilquality.org.au/factsheets/potassium

40 Quinlan, R, and Wherret, (2016) WA Potassium – Fact Sheet, Soilquality.org.au, http://www.soilquality.org.au/factsheets/potassium

FEEDBACK

However, it is advised not to drill K at rates higher than 15 kg/ha and to band fertiliser away from seed.[41]

In paddocks with severe K deficiency (over 30 mg/kg), K is best applied early in the season (up to four weeks after seeding) to maximise crop response, as shown in Figures 11 and 12.

Figure 11: *Impact of potassium supplied at different wheat growth stages on the number of wheat heads per pot.*[42]

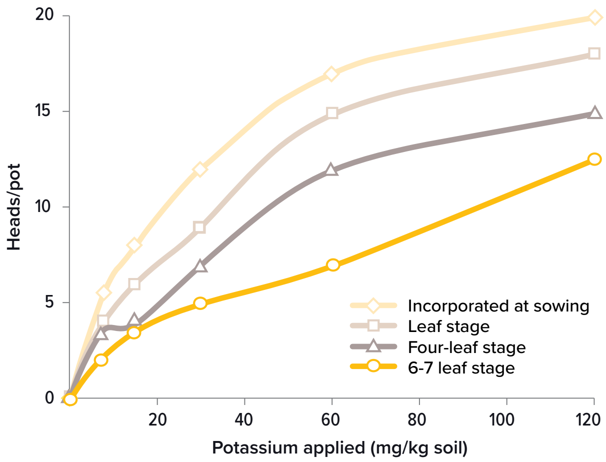
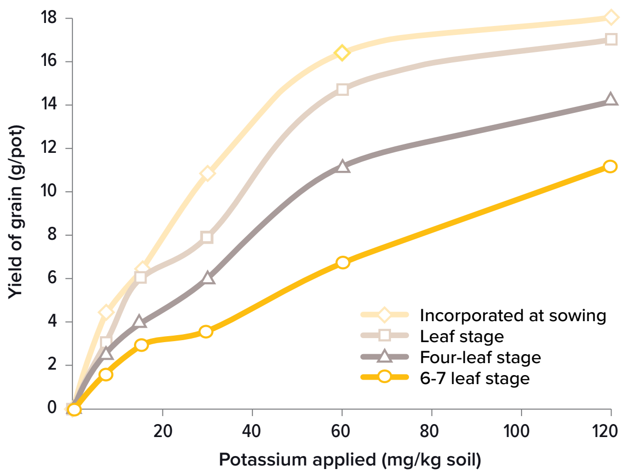


Figure 12: *Impact of potassium supplied at different wheat growth stages on wheat grain yield per pot.*[43]



41 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

42 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

43 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

4.7 Sulfur

Sulfur is part of all living cells and an important part of three of the 21 amino acids that form proteins.[44]

It is also a critical component in the enzyme responsible for converting the NO_3^- form of N to amino acids and is essential for N fixation in legumes and chlorophyll formation.

Sulfur deficiency is rare in WA wheat systems due to previous widespread use of superphosphate (which contains 10 percent S). But it can occur when organic matter mineralisation slows during cold weather and following high rainfall on acidic sandy soils.

Continual use of compound fertilisers that contain little or no S will also increase the risk of S deficiency.

Research has found addressing visual S deficiency in wheat with use of sulphate of ammonia can quickly address the problem without significant yield loss.[45]

There is a poor relationship between the critical soil S test value measured in the 0-10 cm layer and wheat yield response, however a better relationship exists between the critical soil S test value measured in the 0-30 cm layer and wheat yield.[46]

A tissue test for N to S ratio higher than 19:1 often indicates S deficiency.[47]

Early deficiency is occasionally seen in crops growing on sandy soils in wetter areas, but plants generally recover without any yield loss.

Continual use of compound fertilisers that contain little or no S will increase the risk of S deficiency.

WA grainbelt soils typically have soil pH values of less than 5.5 in the 0-10 cm layer. Nevertheless, sulphate sorption is generally low for WA soils in the 0-10 cm soil layer due to low clay content.

Also, the presence of P — which is more strongly adsorbed than S — reduces the capacity of the soil to adsorb S.

Sulphate adsorption is known to increase with soil depth due to increasing clay content of the soil and decreasing P and pH. As a result, there can be significant amounts of S contained in the subsoil — especially in soil profiles with soil pH of less than 5.0.

Crop S requirements are closely linked to the amount of available N — a reflection of the similar role the nutrients have in protein and chlorophyll formation.

Sulfur deficiency is typically unlikely to be an issue when the bulk of crop N is sourced from mineralised N rather than fertiliser N.

As a general rule, fertiliser N and S should be supplied in a ratio of 5:1 (N:S) on sandy textured soils.[48]

Tissue testing of the youngest emerged leaf can determine crop S status. Levels below 0.3 percent are indicative of a deficiency.[49]

If using a whole-top plant test, levels below 0.15 percent in whole shoots at the boot stage are likely to be deficient.

Nitrogen to S tissue test ratios higher than 19:1 are also indicative of S deficiency.[50]

---

44 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

45 GRDC (2015) Hot Topic Sulfur strategies for the western region, GRDC, www.grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region

46 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

47 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

48 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

49 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

50 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes

Topdressing 10-15 kg/ha of S as gypsum or ammonium sulphate tends to overcome deficiency symptoms. Foliar sprays tend to be unable to supply enough S for plant needs.

MORE INFORMATION

GRDC-DPIRD MyCrop and MyCrop app: https://www.agric.wa.gov.au/mycrop

4.8 Micronutrients

The most likely limiting micronutrients in WA wheat systems are copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn).[51]

Inadequate supplies can reduce wheat growth and grain yields and lead to inefficient use of N and soil moisture.

Traditionally, cultivation tended to distribute micronutrients through the topsoil. But the introduction of no-tillage and one-pass seeding equipment has led to more limited physical distribution.

Tissue tests are the best way to identify micronutrient deficiencies.

Soil tests typically have low reliability because micronutrients are present in such low quantities.

Visual crop symptoms can be a guide to micronutrient deficiencies, but some symptoms may mimic other unrelated problems.

For example, symptoms of a Cu deficiency in cereals can resemble symptoms of frost, disease or drought — and even a Mo deficiency can produce white heads. Micronutrient deficiencies may also be temporary or transient due to cold weather, drought or slow root growth.

51 GRDC (2016) Western Wheat GrowNotes™, Section 5.8 Pg 18 Potassium, GRDC, www.grdc.com.au/GrowNotes