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GRAINS RESEARCH & DEVELOPMENT CORPORATION

BARLEY

SECTION 5

NUTRITION AND FERTILISER

ORGANIC MATTER | BALANCED NUTRITION | INCREASING COMPLEXITY OF NORTHERN REGION SOILS | UNDERSTANDING SOIL PH | HIERARCHY OF CROP FERTILITY NEEDS | CROP REMOVAL RATES | NITROGEN | NITROGEN VOLATILISATION AND DENITRIFICATION | CURRENT GENERAL IN-CROP NUTRITIONAL LEVELS FOR NITROGEN | PHOSPHORUS | SULFUR | POTASSIUM | DEEP PLACED PHOSPHORUS, SULFUR AND POTASSIUM | CURRENT GENERAL PRE-PLANT NUTRITIONAL LEVELS FOR ZINC AND MICRONUTRIENTS | NUTRITIONAL DEFICIENCIES | SOIL TESTING | PLANT AND/OR TISSUE TESTING FOR NUTRITION LEVELS | NUTRITION EFFECTS ON THE FOLLOWING CROP | PADDOCK NUTRITION

SECTION 5

Nutrition and fertiliser

Adequate nutrition is essential for good plant growth and development, yield and grain quality. Nutritional requirements vary depending on potential yield and soil fertility status. Nitrogen (N) rates required will vary depending on whether you are trying to meet malt specifications, use the crop for grazing or maximise the yield of a feed variety. Soil tests and nutrient budgeting are useful ways of measuring soil fertility and calculating fertiliser requirements before sowing.

Historically, rates of fertiliser application to barley crops have been low. Barley was perceived to perform well on poor soils and in low-fertility situations. This is not true; in fertile soils, barley yields are comparable to those wheat without necessarily producing a protein level above that acceptable for malting specifications. [1]

Management of N availability is vital to achieve optimal yields and quality in your barley crop. Unlike wheat, which attracts premiums for high protein, malting barley can attract a premium if protein falls between 9 and 12%. A protein target of 12% will also maximise a barley crop's yield potential. [2]

More information

http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-issue-97-MarApr-2012-Supplement-More-profit-from-nutrition

A large percentage of Queensland's barley crop is classified as feed, with protein levels >12%. Older cultivation or double-crop situations with lower soil N supplies can produce malt-grade barley but skill is needed to balance the requirement for N to maximise yield without over-fertilising and increasing the protein level.

When fertiliser prices peaked in 2008, questions were raised about the cost effectiveness of these inputs. New information was sought on best practice for yield and profitability. The result was the Grains Research and Development Corporation (GRDC) More Profit from Crop Nutrition initiative. [3]

5.1 Organic matter

More information

http://www.grdc.com.au/GRDC-Guide-ManagingSoilOrganicMatter

Organic matter has a fundamental and necessary place in soils. It helps to ameliorate or buffer the harmful effects of plant pathogens and chemical toxicities. It enhances surface and deeper soil structure, with positive effects for infiltration and exchange of water and gases, and for keeping the soil in place, i.e., reducing erosion. It improves soil water-holding capacity and, through its high cation-exchange capacity, prevents the leaching of essential cations such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na). Most importantly, it is a major repository for the cycling of nutrients and their delivery to crops and pastures.

Increasing soil organic matter levels and regularly using legumes in rotations will provide a native supply of N and reduce N fertiliser requirements and increase profitability.

1 Procrop Barley Growth & Development, Industry & Investment NSW 2010. http://www.dpi.nsw.gov.au/data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

2 DAFF (2012) Barley planting, nutrition and harvesting. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

3 M Blumenthal and I Fillery (2012) More profit from crop nutrition. GRDC Ground Cover Supplement 16 Feb 2012, http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-issue-97-MarApr-2012-Supplement-More-profit-from-nutrition/More-profit-from-crop-nutrition

For every 0.5% of organic carbon (OC) (0-10 cm) approximately 13 kg N/ha of mineral N is supplied from soil organic matter in the top 30 cm over a typical growing season. This N is released slowly over the growing season and not prone to losses. [4]

Dalal and Chan (2001) reported that the effects of land clearing and cropping in reducing soil organic matter (SOM) levels resulted from changes in soil temperatures, moisture fluxes and aeration, increased soil loss through erosion, reduced inputs of organic materials, increased export of nutrients in harvested product and exposure of protected organic matter with cultivation (Figure 1).

Declining levels of SOM have implications for soil structure, soil moisture retention, nutrient delivery and microbial activity. However, probably the single most important effect is the decline in the soil's capacity to mineralise organic N to plant-available N. In the original 83-paddock study of Dalal *et al*., N mineralisation capacity was reduced by 39–57%, with an overall average decline of 52%. This translated into reduced wheat yields when crops were grown without fertiliser N. A healthy soil with good levels of organic matter and moisture can mineralise up to 1 kg N/day in warm or summer conditions.

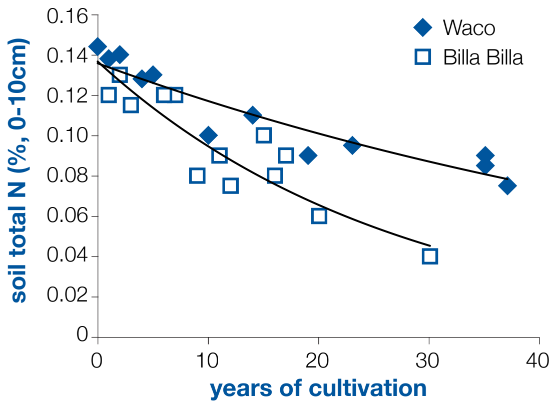

Figure 1: Graph of decline in soil total N with years of cropping. The decline was greater for the Billa Billa soil (clay content 34%) than the Waco soil (clay content 74% clay) .

Soil organic matter is an under-valued capital resource that needs informed management. Traditional cropping practices have dramatically reduced SOM levels and its nutrients are of far more value than soil carbon (C) itself (Figure 2).

Modern farming practices that maximise water-use-efficiency for extra dry matter production are key to protecting SOM. Greater cropping frequency, crops with higher yields and associated higher stubble loads, pasture rotations and avoiding burning or baling will all help growers in the northern region to maintain SOM. [5]

4 Where does fertiliser nitrogen finish up? http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Where-does-fertiliser-nitrogen-finish-up#sthash.VyBrVj53.dpuf

5 D Lawrence, S Argent, R O'Connor, G Schwenke, S Muir, M McLeod (2013) Soil organic matter what is it worth to grain production and what practices encourage it, GRDC Update Papers 16 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Soil-organic-matter-what-is-it-worth-to-grain-production-and-what-practices-encourage-it

More information

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Soil-organic-matter-what-is-it-worth-to-grain-production-and-what-practices-encourage-it

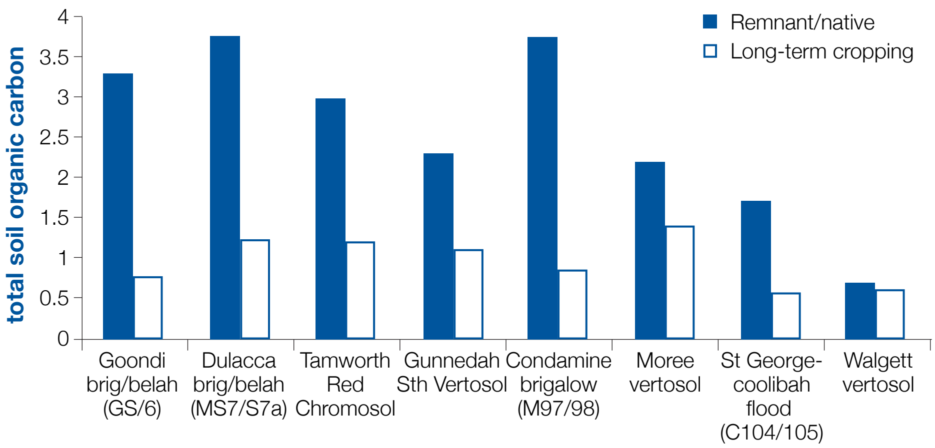

Figure 2: The decline of soil organic carbon with long-term cropping systems.

5.1.1 Current situation

Current organic C and N levels in northern grains cropping soils reflect previous land use and management, as well as other factors such as rainfall, ambient temperature and soil type. There will be substantial within-paddock and between-paddock variation at a specific location, as well as variation across the whole northern region. In fact, differences between the extremely low and high values for particular localities can be as much as 4-fold. As a result, it may be near impossible to categorically state benchmark values for localities and/or soil types without examining masses of archived soil testing data, with the inherent problems of which technique was used for measurement, or embarking on a new comprehensive testing program. [6]

5.1.2 Options for reversing the decline in soil organic matter

Reversing the decline in SOM can be achieved by increasing organic inputs while reducing losses (Table 1).

Table 1: Practices to increase soil organic matter (SOM)

Increase organic inputs by:	Reduce losses of C and N by:
Increasing frequency of well-managed, highly productive pasture leys	Eliminating stubble burning or baling of paddocks
Increasing crop yields	Minimising fallowing
Retention of all crop residues	Taking measures to reduce erosion
Application of manures and recycled organic materials to the soil	Reducing tillage because excessive tillage leads to greater rates of SOM decomposition and erosion losses

Source: Adapted from Schwenke 2004, Chan et al. 2010.

Arguably the most direct, effective means of increasing SOM levels is through the use of legume-based pastures. The rotation experiments of I Holford and colleagues at Tamworth, NSW, (Holford 1981; Holford *et al*. 1998) and R Dalal and colleagues in south-eastern Queensland (Dalal *et al*. 1995; Strong *et al*. 1996) provide good evidence of this. An example is given in Table 2.

The greatest gains in soil C and N, relative to the wheat monoculture, were made in the 4-year grass–legume ley, with increases of 550 kg total N/ha and 4.2 t organic C/ha. The chickpea–wheat rotation fared no better than the continuous wheat system. The shorter (1–2 years) lucerne and annual medic leys resulted in marginal increases in soil organic C and N (Table 2).

[6] D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, http://www.grdc.com.au/GRDC-Booklet-ManagingFertiliserN

Clearly, time and good sources of both C and N are required to build up SOM, which is exactly what the 4-year grass–legume ley provided (Dalal *et al*. 1995; Hossain *et al*. 1996*a*). Nitrogen was supplied via N_2 fixation by the lucerne and annual medic in the pasture, with most of the C supplied by the grasses, purple pigeon grass and Rhodes grass (Hossain *et al*. 1995). There were no inputs of fertiliser N in any of the treatments in Table 2. [7]

Table 2: Effects of different rotations on soil total N and organic C (t/ha) to 30 cm and as gain relative to continuous wheat

Rotation	Wheat crops	Soil total N		Organic C	
		0–30 cm	Gain	0–30 cm	Gain
Grass/legume ley 4 years	0	2.91	0.55	26.5	4.2
Lucerne ley (1–2 years)	2–3	2.56	0.20	23.5	1.2
Annual medic ley (1–2 years)	2–3	2.49	0.13	23.1	0.8
Chickpeas (2 years)	2	2.35	0.00	22.0	0.0
Continuous wheat 4 years	4	2.36	–	22.3	–

Source: Hossain et al. 1996a.

Impact of fertiliser N inputs on soil

If the rates of fertiliser N are sufficiently high, the effects can be positive. In the Warra experiments, both soil organic C and total N increased marginally (3–4%) over an 8-year period when no-till continuous wheat, fertilised at a rate of 75 kg N/ha, was grown. This contrasts with decreases of 10–12% in soil organic C and N in the non-fertilised continuous wheat and chickpea–wheat plots. The result was much the same in the NSW Department of Primary Industries (DPI) experiments in northern NSW. At the Warialda site, for example, SOM increased during 5 years of cropping, but only where fertiliser N had been applied to the cereals.

It is clear from the above examples that building of SOM requires N. It works in two ways. First, the fertiliser or legume N produces higher crop/pasture yields and creates more residues that are returned to the soil. Then, these residues are decomposed by the soil microbes, with some eventually becoming stable organic matter or humus. The humus has a C/N ratio of about 10 : 1, i.e. 10 atoms of C to 1 atom of N. If there are good amounts of mineral N in the soil where the residues are decomposing, the C is efficiently locked into microbial biomass and then into humus.

If, on the other hand, the soil is deficient in mineral N, then more of the C is respired by the soil microbes and less is locked into the stable organic matter.

There is published evidence that applied fertiliser N enhances residue decomposition and its conversion into humus (see, for example, Moran *et al*. 2005). Several possible mechanisms are summarised by Baldock and Nelson (2000). [8]

More information

GRDC Nitrogen booklet: http://www.grdc.com.au/GRDC-Booklet-ManagingFertiliserN

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/BFDC-Interrogator

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Selecting-cultivars-for-better-use-of-banded-fertilizer

5.2 Balanced nutrition

To obtain the maximum benefit from investment, fertiliser programs must provide a balance of required nutrients. There is little point in applying enough N if phosphorus (P) or zinc (Zn) deficiency is limiting yield. To make better crop nutrition decisions, growers need to consider the use of paddock records, soil tests and test strips.

Soil fertility and fertiliser management with attention to N and P is essential to optimise yield. Grain protein below about 10.5% in combination with low yields indicates N deficiency. Where the level of protein is consistently <10%, at least 50 kg/ha of N can

[7] D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, http://www.grdc.com.au/GRDC-Booklet-ManagingFertiliserN

[8] D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, http://www.grdc.com.au/GRDC-Booklet-ManagingFertiliserN

normally be applied at sowing or up to the five-leaf stage to increase yields whilst maintaining malting quality. High fertility paddocks usually produce grain protein too high for malting grade. High rates of N can optimise feed-grain yields. [9]

Monitoring of crop growth during the season can assist in identifying factors like water stress, P or Zn deficiency, disease or other management practices responsible for reducing yield. [10]

5.2.1 Paddock records

Paddock records help:

- establish realistic target grain yield/protein levels prior to planting;
- modify target yield/protein levels based on previous crop performance, planting soil moisture, planting time, fallow conditions, expected in-crop seasonal conditions and grain quality requirements;
- determine appropriate fertiliser type, rate and application method; and
- compare expected with actual performance per paddock and modify fertiliser strategies to optimise future yield/protein levels.

The longer paddock records are kept, the more valuable they become in assessing future requirements. [11]

5.3 Increasing complexity of northern region soils

The northern grains region occupies ~4 million ha across northern and central NSW, and southern and central Queensland. The cropping system is dominated by winter and summer cereals (wheat, barley and sorghum) with a relatively low frequency of grain legumes (chickpea and, to a lesser extent, mungbean, field pea and lupins).

The main cropping soils are Vertosols, Chromosols and Sodosols Intrinsic soil fertility was high, especially on the Vertosols, but this has declined over time such that a significant proportion of the crop's nutrient requirement is now supplied by fertilisers.

There is widespread use of starter P, N and Zn fertiliser, while continued nutrient removal in grain is expected to increase incidence of deficiencies of other nutrients such as K and sulfur (S). Indeed, negative nutrient budgets continue to be recorded across the region.

An assessment of the decline in reserves across the Queensland cropping belt (Bell *et al*. 2010) showed that, compared with adjacent uncropped reference sites, cropped soils across all regions contained only 60% (+5%) of the organic C, 48% (+6%) of total organic N, 36% (+5%) of the particulate organic N, 68% (+14%) of the total inorganic P and 55% (+5%) of the exchangeable K reserves.

This depletion is resulting in increasingly complex nutrient management decisions for growers, with a recent survey of grain nutrient concentrations in wheat (M Bell, K Klepper and D Lester, unpublished data) suggesting significant proportions of the commercial grain crop showed low–marginal status of one or more of N, P, K and S.

Until recently, fertiliser use in parts of the northern grains region was dominated by N inputs, with P and possibly Zn applied as starter fertilisers at planting—often with P rates still much less than rates of crop removal. There is increasing evidence of yield constraints due to concurrent deficiencies of P, K and S, with soil tests indicating the most severe depletion of reserves of P and K occurring in the layers immediately below

9 P Matthews, D McCaffery, L Jenkins (2014) Winter crop variety sowing guide, NSW DPI 2014, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

10 DAFF (2010) Nutrition management. Overview. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

11 DAFF (2010) Nutrition management. Overview. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

More information

Australian Agronomy Conference Paper: http://www.regional.org.au/au/asa/2012/nutrition/8045_bellm.htm

the top 10 cm of the soil profile (i.e.10–30cm). These layers are important for nutrient supply when topsoil root activity is limited by dry conditions but crop growth continues, utilising subsoil moisture (and nutrient) reserves.

Uncertainty remains about the ability of soil tests to accurately predict responsiveness to P, K and S fertilisers. [12]

5.4 Understanding soil pH

A soil pH in calcium chloride ($CaCl_2$) of 5.2–8.0 provides optimum conditions for most agricultural plants. All plants are affected by extremes of pH but there is wide variation in their tolerance of acidity and alkalinity. Some plants grow well over a wide pH range, whereas others are very sensitive to small variations in acidity or alkalinity. [13]

Microbial activity in the soil is also affected by soil pH, with most activity occurring in soils of pH 5.0–7.0. Where extremities of acidity or alkalinity occur, various species of earthworms and nitrifying bacteria disappear.

Soil pH affects the availability of nutrients and how the nutrients react with each other. [14]

At a low pH, beneficial elements such as molybdenum (Mo), P, Mg, S, K, Ca, N and other elements may become toxic (Figure 3). Maintain soil pH($CaCl_2$) between 5.5 and 6.5 to achieve maximum P availability for crops.

[12] M Bell, D Lester, L Smith, P Want (2012) Increasing complexity in nutrient management on clay soils in the northern grain belt—nutrient stratification and multiple nutrient limitations. Australian Agronomy Conference. Australian Society of Agronomy/The Regional Institute, http://www.regional.org.au/au/asa/2012/nutrition/8045_bellm.htm

[13] B Lake (2000) Understanding soil pH. NSW Agriculture, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf

[14] B Lake (2000) Understanding soil pH. NSW Agriculture, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf

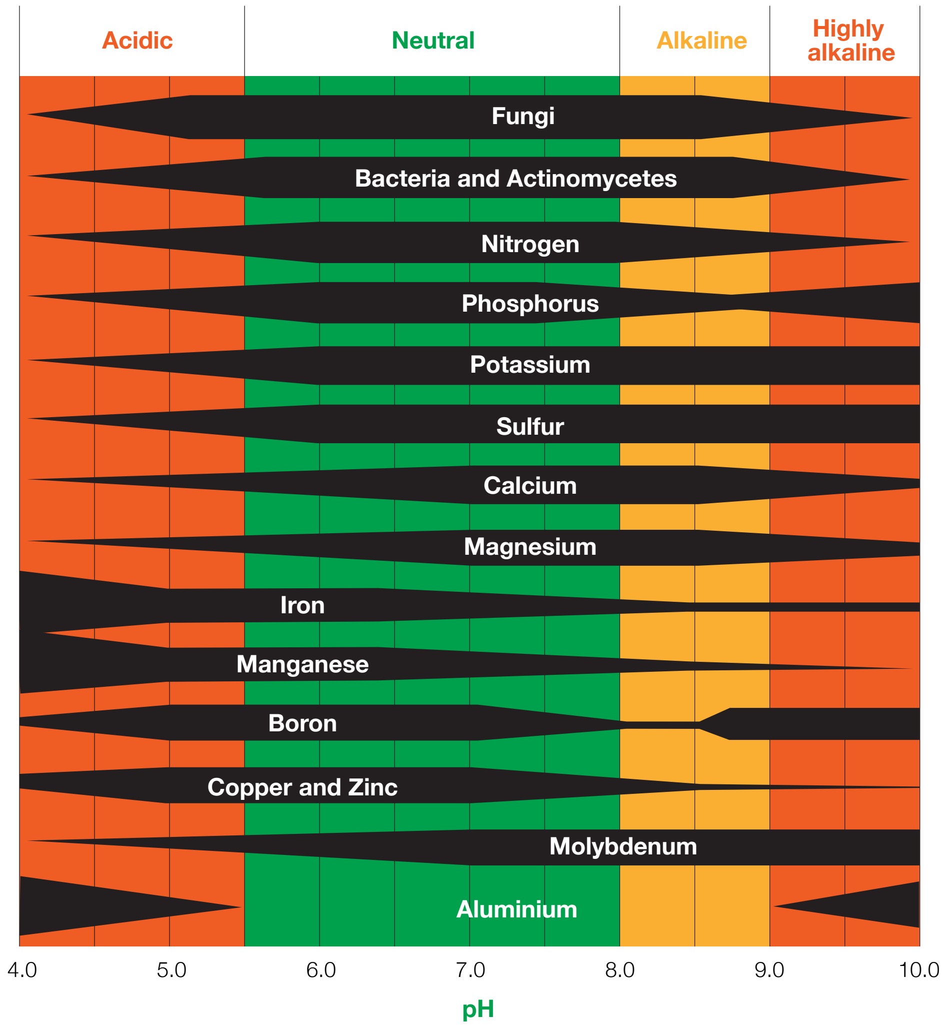

Figure 3: Effect of pH($CaCl_2$) on the availability of soil nutrients. (Source: After Trough.)

The two main laboratory methods employed in Australia to determine pH use either $CaCl_2$ or water.

Soil pH in calcium chloride

This is the standard method of measuring soil pH in all states other than Queensland. An air-dry soil sample is mixed with five times its weight of a dilute concentration (0.01 m) of $CaCl_2$, shaken for 1 h and the pH is measured using an electrode. The results are usually expressed as pH($CaCl_2$).

More information

For more information on crop-specific reactions to soil pH levels, download: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf

Soil pH in water

Distilled water is used in place of 0.01 m $CaCl_2$, and results are expressed as pH(w). The pH($CaCl_2$) test is the more accurate of the two pH tests, as it reflects what the plant experiences in the soil. The values of pH($CaCl_2$) are normally lower than pH(w) by 0.5–0.9. A useful, but not consistently accurate, conversion is to subtract 0.8 from the pH(w) to obtain a pH($CaCl_2$) value. The difference between the methods can be significant when interpreting results and it is important to know which method has been used, especially if pH figures derived some years apart are being compared to assess any pH fluctuations. [15]

[15] B Lake (2000) Understanding soil pH. NSW Agriculture, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf.

5.5 Hierarchy of crop fertility needs

Current research by Department of Agriculture, Fisheries and Forestry Queensland (DAFF) on the Darling Downs confirms a hierarchy of crop fertility needs. There must be sufficient plant-available N to get a response to P, and there must be sufficient P for S and/or K responses to occur. [16]

Liebig's law of the minimum, often simply called Liebig's law or the law of the minimum, is a principle developed in agricultural science by Carl Sprengel (1828) and later popularised by Justus von Liebig. It states that growth is controlled not by the total amount of resources available, but by the scarcest resource (i.e. limiting factor) (Figure 4). [17]

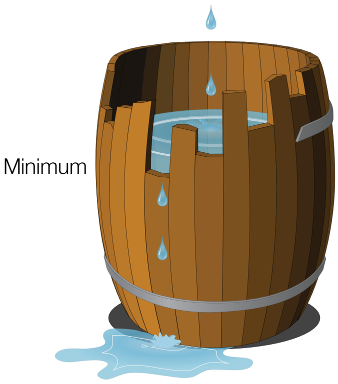

Figure 4: Leibig's law or law of the minimum.

Additive effects of N and P appear to account for most of the above-ground growth and yield response. [18]

More information

GRDC Update Paper: http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Observations-on-a-general-decline-in-fertility-of-multiple-nutrients

5.6 Crop removal rates

Nutrients removed from paddocks need to be replaced at some point to sustain production (Table 3). 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.

Table 3: Average nutrients removed by barley crops—values are kg/ha

	Yield	N	P	K	Ca	Mg	S	Zn
Irrigated wheat grain	7000	125	24	35	3.5	10	3	200
Dryland wheat grain	2000	40	7	10	1.5	2.8	5.5	60

The yield potential of a crop will be limited by any nutrient the soil cannot adequately supply. Poor crop response to one nutrient can often be linked to a deficiency in another nutrient or other management techniques. Crop response can also be linked to soil constraints such as acidity, sodicity or salinity, problems with beneficial soil microorganisms, or presence of pathogens such as nematodes.

To attain optimum yields, an adequate supply of each nutrient is necessary. However, it is important to realise that only a small proportion of the total amount of an element in the soil may be available for plant uptake at any one time. For nutrients to be readily

16 D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers 7 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs

17 Anon. Liebig's law of the minimum, http://en.wikipedia.org/wiki/Liebig's_law_of_the_minimum

18 D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers 7 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs

available to plants, they must be present in the soil solution (the soil water), or easily exchanged from the surface of clay and organic matter particles in the root-zone, and be supplied when and where the plant needs it.

Temperature and soil moisture content affect the availability of nutrients to plants, and the availability of nutrients also depends on 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.

Lack of movement of nutrients, combined with current farming methods (e.g. no-till), is resulting in stratification of nutrients, with concentrations building up in the surface of the soil where they are not always available to plants, depending on the seasonal conditions. Often, on Queensland's Western Downs and in central Queensland, winter cereals are deep-sown into moisture that is below the layer where nutrients have been placed or are stratified, and this has implications for management and fertiliser practices. [19]

Reserves of mineral nutrients such as P have been run down over several decades of cropping with negative P budgets (removing more P than is put back in by fertilisers or crop residues). This trend has accelerated as direct-drill cropping has improved yields and crop frequency, removing even more P from the soil.

Consequently, limited P is now constraining yields in parts of the northern grains region, particularly in the vertosols (black and grey cracking clays). High native fertility has been depleted, and the move to no-till/minimum-tillage has reduced the opportunities to incorporate P and other immobile nutrients into the soil. [20]

Analysing grain for nutrient content provides additional information when monitoring soil fertility by accounting for the amount of nutrient removed with each harvest. [21]

5.7 Nitrogen

5.7.1 Nitrogen supply and grain protein content

Nitrogen is a primary constituent of protein, so adequate soil N supply is essential for producing wheat with a high protein content. Supply of N is shaped by a number of factors in the farming system (Figure 5).

[19] DAFF (2012) Wheat—nutrition. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition

[20] GRDC (2012) Crop nutrition. Northern region—phosphorus management. GRDC Fact Sheet Nov. 2012, http://www.grdc.com.au/~/media/578CC7FEE649428D9C4C90B7461537D0.pdf

[21] GRDC (2012) Crop nutrition. Northern region—phosphorus management. GRDC Fact Sheet Nov. 2012, http://www.grdc.com.au/~/media/578CC7FEE649428D9C4C90B7461537D0.pdf

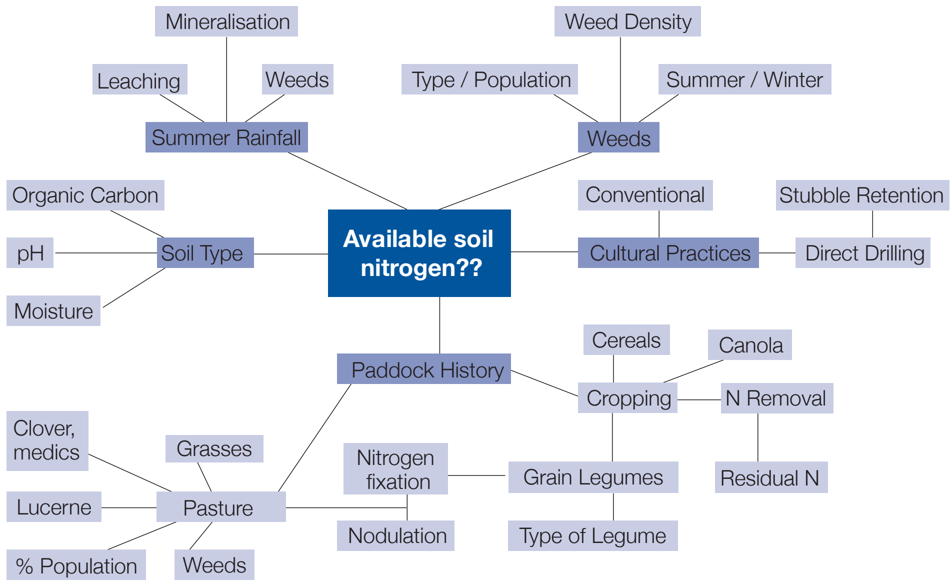

Figure 5: Factors influencing available soil nitrogen. (Source: Incitec Pivot Ltd.)

Grain protein is modified by the grain yield of the crop—increasing grain yield has a diluting effect on grain protein, i.e. yield and protein are inversely proportional (Figure 6).

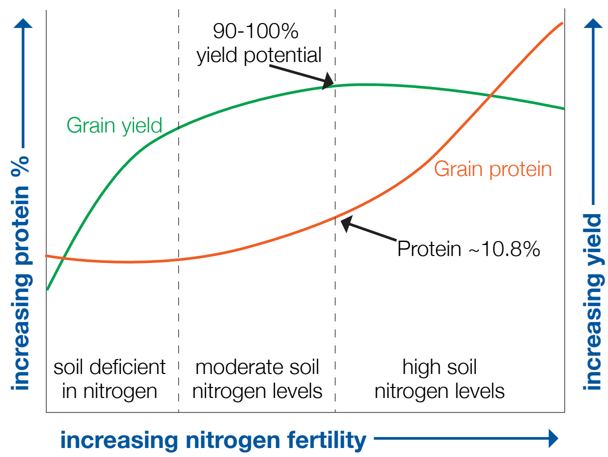

Figure 6: The relationship between yield and protein. (Source: Incitec Pivot Ltd.)

This explains why a larger proportion of the crop is of a high protein in drier seasons or seasons of low grain yield, whereas high yields can be produced but may be at a lower protein level in wetter years. Nitrogen fertility can be extremely variable from one year to the next.

The cycling of N between atmosphere, soil, and plants and animals is depicted in Figure 7.

GRDC Video

http://www.grdc.com.au/Media-Centre/GRDC-Gallery/Video/3jDrtfg95Po

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More information

GRDC Update Papers:
http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Have-we-got-the-foundation-of-N-nutrition-right#sthash.kGrs8NES.dpuf

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Will-low-protein-become-the-new-norm

GRDC Booklet:
http://www.grdc.com.au/Resources/Bookshop/2013/05/Managing-Legume-and-Fertiliser-N-for-Northern-Grains-Cropping

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Factors-affecting-how-much-N-is-lost-and-how-much-is-left-over-time

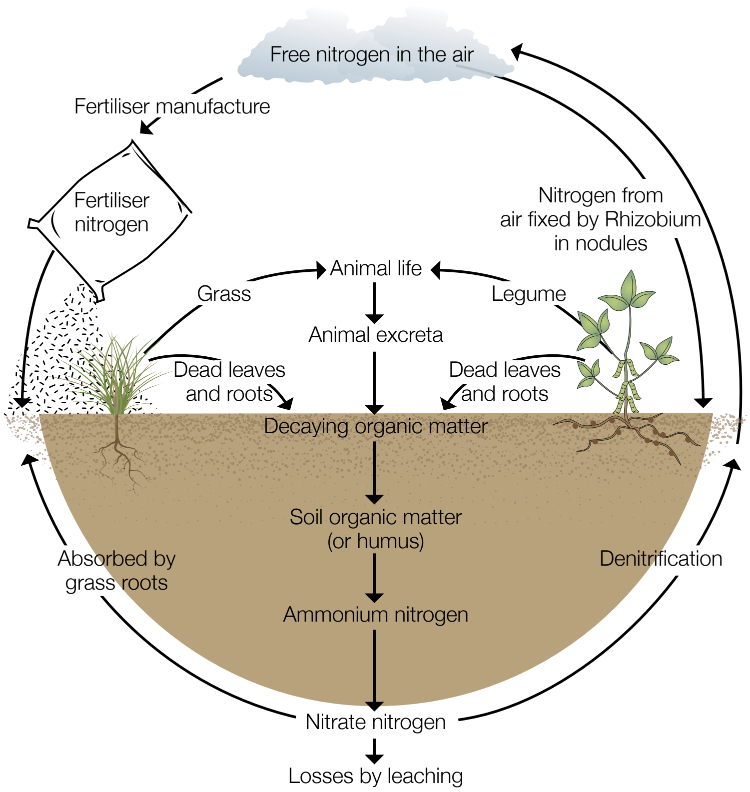

Figure 7: The soil nitrogen cycle.

5.8 Nitrogen volatilisation and denitrification

Ammonia volatilisation (Figure 8) occurs when urea is surface-applied without incorporation. After application, urea dissolves in water and in the presence of urease, forms ammonium ions (NH_4^+). If there are insufficient adsorption sites at the soil surface for the ammonium ions, ammonia (NH_3) gas can form as the soil dries out, e.g. in the heat of the day following overnight dew. Such losses are greatest in alkaline (high-pH) soils, in which hydroxyl (OH^-) ions are present in high concentrations. [22]

It is known to be safer to incorporate than to rely on surface spreading, but many farmers in the northern region practice pre-season broadcasting and in-season topdressing of wheat crops. Splitting N application between sowing and in-crop allows growers to lower their financial risk on fertiliser application by allowing seasonal conditions to drive decisions on how much to spend on nitrogen, but this can come at a cost of additional yield

Most farmers try to apply fertiliser ahead of predicted rain, but what happens if rain does not fall as predicted? Is all of the N really lost to the air in 1 or 2 days? International research literature lists the range of measured losses from 0 to almost 100%, but there are very few instances of losses greater than ~40% of that applied, with most studies finding only ~10% loss.

In the 2008 and 2009 GRDC Adviser Updates, researchers detailed the factors that drive the process of N volatilisation from fertiliser, along with the results of some laboratory incubation experiments (Schwenke *et al*. 2008, 2009).

The following is a brief summary of the many factors involved:

1. Soil pH. There is more loss at higher pH. Dissolving urea granule creates a high pH zone.
2. Temperature. The hotter it is, the greater the potential there is for ammonia loss.

[22] Source: Incitec Pivot Ltd

3. Soil moisture. Wet soil dissolves fertiliser but does not move N into the soil.
4. Calcium carbonate ($CaCO_3$). Lime in the soil reacts directly with ammonium sulfate increasing, loss.
5. Soil clay content. Clay in soils adsorbs ammonium-N, decreasing potential for loss.
6. Soil buffer capacity. Clays in soil absorb changes in soil pH.
7. Biological activity. Ammonium is converted to nitrate, which is safe from volatilisation.
8. Wind. Windy conditions at the soil surface lead to greater loss.
9. Rain. Rain moves dissolved fertiliser into contact with soil clays, away from wind.
10. Depth of fertilizer. Ammonia must be at the surface to volatilise. Incorporation reduces loss.
11. Crop canopy. Some ammonia in air can be re-absorbed by a growing crop canopy and the canopy also reduces the wind intensity at the soil surface.
12. Residues/litter. Residues can strand the fertiliser at the surface. Urease enzyme is present in residues.
13. Fertiliser type. Only the ammonium form is lost; urea converts to ammonium and nitrate forms are not volatilised.

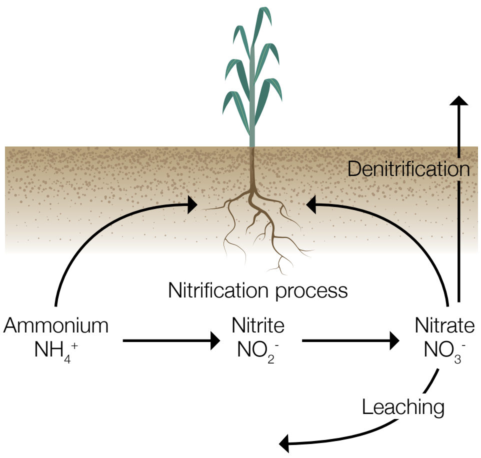

Figure 8: The nitrification process.

In cracking clay soils of the northern grains region, saturated soil conditions between fertiliser application and crop growth can lead to significant N losses from the soil through denitrification. The gases lost in this case are nitric oxide (NO), nitrous oxide (N_2O) and di-nitrogen (N_2). Isotope studies in the northern region have found that these losses can be >30% of the N applied. Direct measurements of nitrous oxide highlight the rapidity of loss in this process.

Nitrogen losses from ammonium sulfate applications were less than from urea in both bare fallows and grass-based perennial pastures. However, ammonium sulfate should be avoided on soils with naturally occurring lime in the surface. [23]

Research funded by GRDC and NSW DPI through a Northern Grower Alliance project (NGA0002) showed that delayed N reliably improved grain protein and maintained grain yield with applications up to early stem elongation, irrespective of the N fertiliser used.

Initial trials of summer fallow broadcast applications have shown that some losses are to be expected but are mostly minor (<10%), unless the soil surface has naturally occurring lime, where losses can be much higher. However, researchers report that naturally occurring lime in the surface soil is quite rare. If in doubt, request a CaCO3 test

More information

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2009/09/NITROGEN-VOLATILISATION-FROM-NORTHERN-CROPPING-SOILS

More information

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency

More information

Australian Grain Consultant Corner: http://www.nga.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf

[23] G Schwenke (2013) Nitrogen use efficiency. GRDC Update Papers 16 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency

More information

GRDC Update Paper: http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Nitrogen-volatilisation-losses-how-much-N-is-lost-when-applied-in-different-formulations-at-different-times

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Barley-agronomy-in-southern-NSW

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Where-does-fertiliser-nitrogen-finish-up

http://www.grdc.com.au/Media-Centre/Media-News/South/2015/06/Model-your-nitrogen-to-account-for-in-crop-mineralisation

during testing. Once will generally be sufficient as lime content does not change with seasons. However, cultivation can bring lime up from lower in the soil profile. In general, current research results so far fit well with the research literature where an average of 10% of applied N is lost from urea added to arable systems. [24]

5.8.1 Nitrogen requirements

Excessive N fertiliser application close to the seed can lead to toxicity problems. Under good moisture conditions, seed can tolerate a maximum of about 25 kg of N/ha without seedling mortality. This amount is based on an 18-cm row spacing and fertiliser banded with the seed.

Deep banding is one method of applying N fertiliser at sowing without causing seedling losses. This requires the use of seeding systems that can separate seed and fertiliser by more than 25 mm. Pre-drilling of N as urea is another option. Alternatively, N fertiliser can be broadcast and incorporated at sowing. [25]

A rule of thumb used by some Queensland growers for producing malting barley is 0.4 kg of N/ha for every mm of available soil moisture. That means that if there is 150 mm of available soil moisture, this will require 60 kg N/ha to produce a barley crop with protein of 8.5–12%. In high-yielding years, grain protein can be reduced through N dilution as grain yield increases. [26]

One method of calculating N requirements is by measuring existing soil N and estimating a target yield and protein and works as follows:

- Calculate available soil water e.g. using HowWet, stored soil moisture and estimated in-crop rainfall.
- Estimate target grain yield and protein percentage based on available moisture (e.g. 3.5 t/ha at 10.1% protein). Crop simulations such as Whopper Cropper can generate yield probabilities for a range of starting soil moisture and sowing dates. Ideal malting barley grain protein is about 11.5% dry (optimum yield) or 10.1% wet at 12% grain moisture. Target for feed barley grain protein is about 12% dry (max. yield) or 10.5% wet at 12.5% grain moisture.
- Calculate how much N will be harvested in the grain. Grain N (kg/ha) = yield (t/ha) x protein% x 1.6 (e.g. for the above target yield and protein 3.5 x 10.1 x 1.6 = 57 kg N/ha).
- Calculate N required to grow the crop. Barley requires roughly twice the amount of N in the grain. Nitrogen required for crop (kg/ha) = grain N x 2 e.g. (3.5 x 10.1 x 1.6) x 2 = 113 kg N/ha.
- Estimate or measure the soil N e.g. use soil tests (including the soil profile to 90 or 120 cm), or previous crop yields and proteins. Include mineralisation (generally about 30 kg N/ha).
- Calculate the extra N required. Extra N required = N required to grow crop – soil N, e.g. with 10 units (kg/ha) of N in the soil and an estimated 30 units to be mineralised and a total of 113 units of N to grow your crop of 3.5 t/ha at 10.1% protein.

The equation will be 113 kg (total N required) – 40 kg (total available or to be mineralised) = 73 kg/ha of N. If using a product such as urea, which is 46% N, you will need 158 kg/ha of urea. (73/0.46) (Table 4). [27]

[24] G Schwenke, A Perfrement, W Manning, G McMullen (2012) Nitrogen volatilisation losses how much N is lost when applied in different formulations at different times. GRDC Update Papers 23 March 2012, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Nitrogen-volatilisation-losses-how-much-N-is-lost-when-applied-in-different-formulations-at-different-times

[25] Procrop Barley Growth & Development, Industry & Investment NSW 2010. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

[26] DAFF (2012) Barley planting, nutrition and harvesting. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

[27] DAFF (2012) Barley planting, nutrition and harvesting. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

Table 4: Indicative N fertiliser required (kg/ha) to produce the target yield (t/ha) of barley with 11.5% grain protein dry.

Target yield (t/ha) at 11.5% protein (dry):		2	3	4	5
Total N required (kg/ha):		75	110	145	180
Cropping history	Estimated available soil N (kg/ha)*	Balance of N required as fertiliser (kg/ha)			
Double-cropped from sorghum	30	45	80	117	152
Fallowed from winter cereal	55	20	55	92	127
Fallow from chickpeas (yielding 0.5–1.0 t/ha)	65	10	45	82	117
Fallow from chickpeas (yielding 1.0–1.5 t/ha)	75	0	35	72	105

Source: Department of Agriculture, Fisheries and Forestry, Queensland.

5.9 Current general in-crop nutritional levels for nitrogen

To meet malt specifications, growers should target protein levels of 10.5–12% to achieve maximum yield and still meet receival standards. As the rate of N supply is increased, yield will generally increase to a maximum level, whereas protein may continue to increase with further N application. Drier or wetter than expected seasonal conditions can significantly change yield potential mid-season, which consequently changes N requirements to meet target protein contents. A cereal crop not attaining 10.5% protein has not maximized its moisture limited yield potential, just as a crop which has higher than 11.5% protein has had excess available nitrogen.

The flexibility of delaying N application can be a risk management strategy for growers to adapt to changing seasonal conditions. When considering in-crop N applications it is critical to know soil N levels at the start of the season. Many paddocks may have high starting soil N levels well in excess of what is required to achieve realistic target yields and maintaining grain protein levels suitable for the production of malting barley. [28]

In 2012, NSW DPI ran N trials on barley at sites near Walgett, Bithramere and Moree in northern NSW. Commander⊕, Bass⊕, Navigator⊕ and Gairdner⊕ barley, were grown at a plant population of 100 plants/m at all three trials sites. In each trial, four rates of N were applied at sowing, namely 0, 40, 80 and 120kg N/ha as granular urea (46% N). Two additional N treatments were implemented: 80 kg N/ha applied at growth stage 31 (GS31, stem elongation); and a split application treatment where 40 kg N/ha was applied at sowing with a further 40 kg N/ha applied at GS31. The in-crop application of N was applied as 50% diluted liquid urea-ammonium nitrate, applied through streamer bars at a water rate of 100 L/ha.

Results from the Bithramere and Moree sites showed that Commander⊕ had the highest yield on average compared with the other varieties. Bass⊕ and Navigator⊕ had similar yield to Gairdner⊕ in these trials. There was a significant N response at all sites, although it was much stronger at the Moree site.

The Walgett site had high levels of starting N (95 kg N/ha), which resulted in grain yield declines in all varieties at the 120 kg N/ha application rate compared with the 80 kg N/ha rate. The split N application gave similar yields as the 80 kg N/ha up-front treatment at all sites and across the four varieties. However, there was one exception with Commander at Bithramere, where the split N treatment provided an 8% yield benefit. (Figure 9*a*). Delaying N application until stem elongation resulted in a significant decrease in yield for Gairdner, Commander and Bass at Moree, while at Bithramere and Walgett there was no significant difference between the delayed N treatment and the 80 kg N/ha up-front (Figure 9).

28 M Gardner, R Brill, G McMullen (2013) A snapshot of wheat and barley agronomic trials in the northern grains region of NSW. GRDC Update Papers 5 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-snapshot-of-wheat-and-barley-agronomic-trials-in-the-northern-grains-region-of-NSW

The protein responses were relatively linear at all sites, but there were significant differences between treatments. The Walgett site was less responsive only increasing protein by 2.5% when moving from 0 to 120 kg N/ha compared with 4.6 and 4.9% for the Moree and Bithramere site, respectively. Commander had the lowest protein content of all varieties, virtually across all N rates (Figure 9*d*, *e*, *f*). Gairdner has been found in previous NSW DPI studies to achieve approximately 1–1.5% higher protein than Commander with the same N input, which was again the case at Moree, Walgett and Bithramere in 2012. Bass, on average, had the highest protein levels across the three sites and protein was approximately 0.4% higher than in Gairdner. Delaying or split applications of N at Moree and Walgett significantly reduced grain protein compared with the up-front application of 80 kg N/ha.

Navigator at Bithramere was the only instance where the average test weight dropped below 70 kg/hL; however, the receival standard for malting barley is 65 kg/hL. On average, across the three sites, Bass had the highest test weight, while Navigator and Gairdner had similar test weights that were lower than Commander (Table 5). Bass and Commander had the highest retention levels of all varieties with averages of 89.1 and 86.9% across the sites. The retention at the Walgett site was approximately 20% less than the other sites, which was a direct result of the high starting soil N levels at this site. Both Gairdner and Navigator were under the receival standard of 70% retention at Walgett; however, Gairdner was most affected with nearly 40% lower retention than Navigator. Gairdner also dropped below the 70% target retention at Moree. In general, the screenings from all sites and varieties were below the receival standard of 7% for malting barley with the exception of Gairdner at Walgett, where screenings were approaching 10%. Bass had the lowest screenings of all varieties, while Commander and Navigator had similar screenings levels (Table 5).

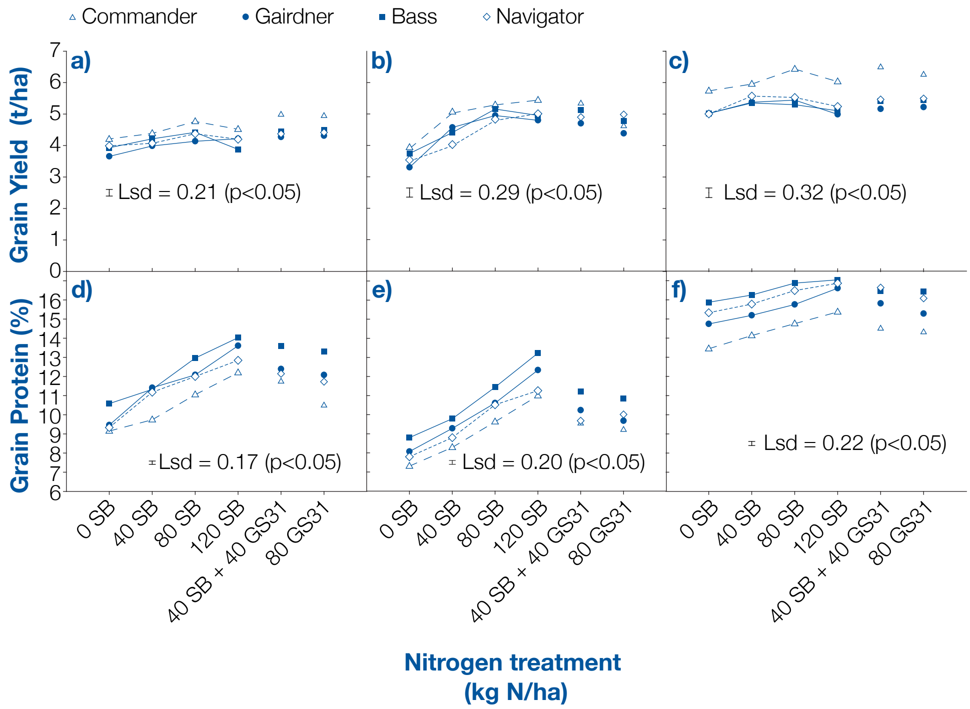

Figure 9: Yield and protein responses of Commander⊕, Bass⊕, Navigator⊕ and Gairdner⊕ barley to six N treatments at (a, d) Bithramere, (b, e) Moree and (c, f) Walgett in 2012.

There has been a trend for new barley varieties to achieve lower protein levels; however, both Navigator⊕ and Bass⊕ appear to be more protein responsive to N applications compared to Commander⊕. The low protein level of Commander⊕ has generally been an advantage to meet malt specifications, but over seasons immediately prior to 2012, extremely low proteins (<9%) have been achieved throughout the region, suggesting that yield may have been sacrificed at this level. The higher protein achievement of Bass⊕ and Navigator⊕ indicates that growers may need to be careful growing these varieties on paddocks with high levels of residual N as it may jeopardise achieving malt specifications. This highlights the need to have some indication of starting soil N levels. Bass and Commander appear to maintain the highest grain quality in terms of meeting malt specifications under a range of N levels. However, Commander still maintains a yield advantage over Bass and it would be slightly better suited to higher N situations. This recommendation comes with the caution that high starting N would increase the risk of lodging in Commander, which may be negated through plant population, planting time or delayed application of N. The Walgett site again highlighted the problems with low retention and high screenings in Gairdner when it is grown under high N conditions and has a dry finish to the season. [29]

Table 5: Average grain quality (test weight (kg/hL), retention (%), screenings (%) and 1000-grain weight (g) for Commander, Gairdner, Bass and Navigator at Walgett, Moree and Bithramere in 2012. Values followed by different letters within each row are significantly different (at P = 0.05).

Site	Quality trait	Commander	Gairdner	Bass	Navigator
Walgett	Test Weight	74.5 a	73.8 b	74.7 a	73.4 b
	Retention %	79.6 a	31.5 d	74.7 b	69.5 c
	Screenings %	3.0 b	9.8 a	2..2 c	3.6 b
	1000GW	41.6 a	38.4 b	39.5 ab	36.4 b
Moree	Test Weight	71.9 b	71.3 c	74.1 a	71.2 c
	Retention %	90.1 b	69.4 d	96.6 a	79.2 c
	Screenings %	4.1 b	4.9 a	0.2 d	2.2 c
	1000GW	40.4 b	41.4 b	45.3 a	39.8 b
Bithramere	Test Weight	70.4 b	70.6 b	72.8 a	68.2 c
	Retention %	71.0 b	75.8 d	96.7 a	87.2 c
	Screenings %	1.7 b	2.8 a	0.6 c	1.7 b
	1000GW	42.0 b	41.3 b	44.6 a	38.6 c

As a general rule, applications of N from sowing to stem elongation increases yield, whereas applications after stem elongation increases protein. The later N is applied, the less time there is for it to be moved into the root uptake zone to be available to the plant:

- N applied during early tillering (GS23–29) has the greatest impact on yield by increasing or maintaining tillers. N applied at this stage is used almost as efficiently as that applied at pre-sowing. About 40–50% of the applied nitrogen is used by the plant.
- Application of N at stem elongation (GS30–40) increases yield by maintaining existing tillers and also increases the protein level in the grain by up to 1%. About 30% of the applied N is used by the plant.
- Application of N at head emergence (GS51–59) has the maximum effect on grain protein. About 20% of the N applied is used by the plant.

Because of the cost and potential economic risks associated with N topdressing, it is best to carefully assess the agronomic state of the crop and the yield potential before applying N.

Do not apply N to crops suffering stresses from drought, waterlogging, disease (foliar or root) or weed competition, as the crop will not respond to increased N and the applied nitrogen may be lost. It is also essential to assess how much N is presently available to the crop.

The difficulty of predicting rainfall events makes topdressing N as granular fertiliser (urea) risky in northern NSW. Split applications are more common in central and southern NSW. For efficient recovery of urea N, moisture needs to move from the surface into the topsoil, carrying the N into the profile, where it makes contact

29 NSW DPI (2013) Northern grains region trial results autumn 2013, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf

More information

GRDC Update Paper
http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Changing-nutrient-management-strategies-in-response-to-declining-background-fertility

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Economics-and-management-of-P-nutrition-and-multiple-nutrient-decline

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Deep-phosphorus-placement-case-study

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/A-calculator-to-assess-the-economics-of-deep-placement-P-over-time

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Improving-fertilizer-decisions-for-P-on-the-Western-Downs

with actively growing roots. A rainfall event of 5mm or more is required soon after application. [30]

5.10 Phosphorus

Phosphorus is essential for seed germination and early root development and for increasing seedling vigour and establishment. Large amounts are taken up during early growth. Phosphorus deficiency at this early stage of growth significantly reduces yield potential, particularly by reducing tiller production and survival.

Wheat, barley and sorghum have a critical requirement for a high soil P concentration around young seedlings in their first 30 days. This is when grain numbers are established and yield potential is determined. [31]

Many of the soils in NSW have low levels of P, and in some areas, P is the limiting nutrient. Low P levels can increase the protein content of the grain, making it unsuitable for malt classification. Phosphorus is immobile in the soil, which means that regardless of soil test results, some P needs to be applied with the seed at sowing at similar rates to those used for wheat.

One method of estimating phosphorus requirements is to allow for P at 5 kg/t target yield. For example, a 3 t/ha barley crop requires 15 kg/ha of P. Application rates should be increased by 20% to compensate for slow root growth and P uptake and moisture uptake in dry years. Delays in the uptake of P to critical levels can delay maturity, which in turn can increase grain screenings. [32]

Phosphorus deficiency is widespread throughout the Darling Downs region with ~60% of all agricultural soils being responsive to phosphorus fertilisers. Low P levels in a high N situation can result in delayed flowering, which affects the yield potential and grain-filling time of the crop. For optimum performance, it is recommended to use a starter fertiliser with P unless levels are already very high (Table 6).

Table 6: Phosphorus recommendations

Bicarb P (mg/kg)	Recommendations
0–10	Response most likely. Apply 8 kg P/ha
11–15	Response likely. Apply 6 kg P
16–20	Response possible. Test strip of 6 kg/ha
>20	Response unlikely

Source: Department of Agriculture, Fisheries and Forestry, Queensland.

It is important to assess the P status of the subsoil periodically. Test the 10–30 cm layer using BSES-P as well as Colwell-P soil tests, and test for K at the same. This will help build a picture of a soil's fertility and the values from the deeper layers can be used to refine your fertiliser strategy (Table 7). [33]

30 Procrop Barley Growth & Development, Industry & Investment NSW 2010. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

31 GRDC (2012) Crop nutrition. Northern region—phosphorus management. GRDC Fact Sheet Nov. 2012, http://www.grdc.com.au/~/media/578CC7FEE649428D9C4C90B7461537D0.pdf

32 Procrop Barley Growth & Development, Industry & Investment NSW 2010

33 GRDC (2012) Crop nutrition. Northern region—phosphorus management. GRDC Fact Sheet Nov. 2012, http://www.grdc.com.au/~/media/578CC7FEE649428D9C4C90B7461537D0.pdf

Table 7: Products used primarily to supply phosphorus, and amount (kg/ha) of each product required for given application rates of P

Product trade name	% P in product	Required rate of application of P (kg/ha)				
		4	6	8	10	15
Mono-ammonium phosphate (MAP)/ Starterfos	22	18	27	36	45	68
Di-ammonium phosphate (DAP)	20	20	30	40	50	75
CK700	8.2	49	73	98	122	183
Granulock ST-Z	20.5	20	24	39	49	73

The combination of fungus and the crop root is known as arbuscular mycorrhiza (AM). Long fallowing can increase the response of deficient soils to P due to the absence of AM. This should not be a major concern for barley as it has a low requirement for AM. Reduced tillage/no-tillage may accentuate the responsiveness of a soil to phosphate fertiliser due to the immobilisation of phosphate in the soil surface. [34]

For more information, see Improving phosphorus fertiliser management on southern Queensland grains farms.

5.11 Sulfur

More information

Barley nutrition and agronomy - do we need sulphur and nitrogen?

Sulfur deficiency can be a problem in areas with a long history of cultivation. If S deficiency is suspected, use a test strip to indicate potential response. It is more likely to occur after short-fallow or double-crop situations, where soil S levels have been depleted by the previous crop.

Evidence of S deficiency in crops following recent wetter seasons has prompted a request for updated information on S cycling in the northern grains region. Key points to consider include:

- S deficiency is not yet widespread.
- Crop residues are important in recycling S in cropping systems.
- Appropriate soil testing strategies are important in future monitoring.

The S cycle has been well characterised over many years (Figure 10). The key processes in northern cropping soils are the reactions between soil solution sulfate and soil organic S, and solution sulfate and adsorbed sulfate and loss of S by leaching. Two important processes not highlighted in Figure 10 are the movement of S from crop residues into the soil directly rather than through an animal, and the tendency for S to accumulate in the soil profile in the form of gypsum.

Most of the S that the crop acquires early in life is most likely derived from immediate release of S from crop residues that remain in the surface soil, and from mineralisation of S from organic matter over the fallow period. Sulfur behaves in a manner similar to N with respect to fallow build-up as an anion (sulfate and nitrate). As micro-organisms consume labile organic matter, they release excess S as sulfate into the soil solution, which is available for plant uptake and/or leaching. This is the same process that releases N as ammonium, which then nitrifies to nitrate.

However, sulfate is not quite as readily leached as nitrate and can remain higher in the soil profile for longer periods. The reason for this is 2-fold. First, sulfate is slightly more reactive with the clay in the soil with some of it is specifically attracted and retained against leaching. Second, as soils dry out, water that may have filled large pores and diluted the S to a soluble form susceptible to leaching retreats to smaller pores and the sulfate becomes more concentrated. As the concentration of sulfate increases, it

[34] DAFF (2012) Barley planting, nutrition and harvesting. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

reaches a critical stage where it begins to react with Ca in solution to form gypsum. Once in the form of gypsum it is not as susceptible to leaching and the movement of S down the profile stalls until conditions again become wet enough to dissolve the gypsum into its constituent parts. This is an extra step in the process and slows movement of S relative to movement of nitrate. One consequence of this is banded layers of gypsum in the subsoil, and the depths of these bands are most likely related to the frequency of periods of inundation.

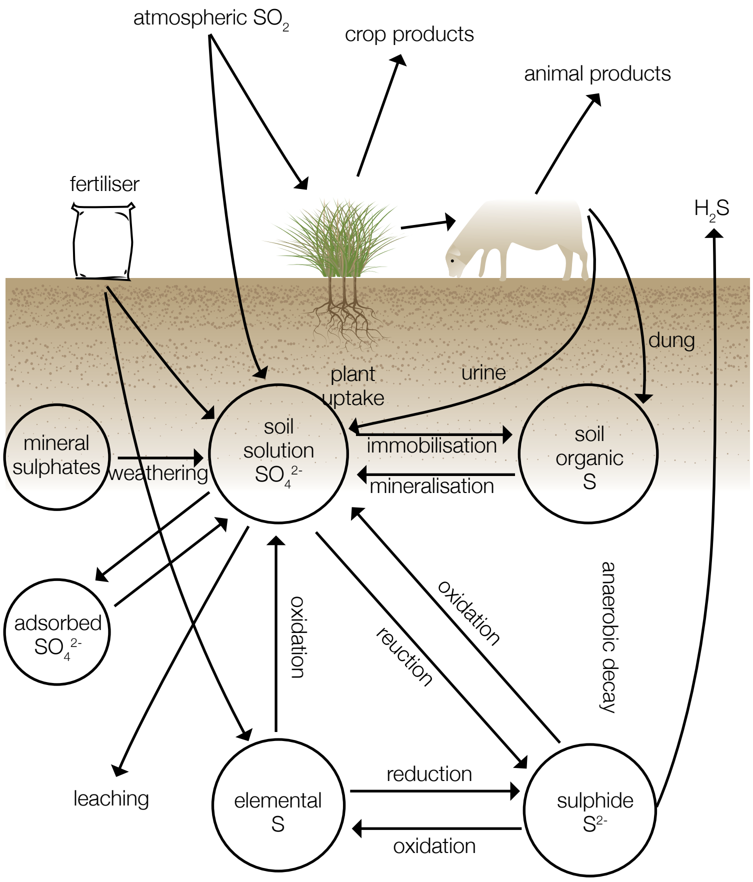

Figure 10: The sulfur cycle (McLaren and Cameron 1996).

Residue S and mineralised organic S most likely constitute the first sources of S for the crop. If these are inadequate because prolonged inundation has moved sulfate beyond the reach of young root systems, then transient S deficiency may be observed. Sulfur deficiency is observed as pale yellowing of the younger leaves in most instances. However, should the root system grow deep enough, it may then find reserves of S in the subsoil from the leaching front and recover from the transient deficiency, hence, the need to sample at a range of depths.

5.12 Potassium

Potassium is found at adequate levels in most Australian soils, so deficiency is rarely seen. It is a major plant nutrient that is required in similar levels to N. Plants that are K-deficient cannot use other nutrients or water efficiently and are less tolerant to stresses such as drought, waterlogging, pests and diseases.

Potassium is very mobile in plant tissues. In deficient plants, it is moved to new growth, so deficiency symptoms appear first in older leaves. The symptoms are yellowing and death (necrosis) of the tips of oldest leaves. In barley, necrotic areas can have a red appearance. Stems may be weakened, resulting in lodging. Restricted K supply during early growth stages may be more harmful than later deficiency. Potassium deficiency can affect leaf area, the amount of dry matter produced in the upper internodes and heads, the number of grains per head, or the seed weight. The root systems of K-deficient plants may also be poorly developed.

Potassium requirements are greatest during the late vegetative and flowering stages.

5.13 Deep placed phosphorus, sulfur and potassium

Several experiments across northern NSW and southern and central Queensland have focused on asking the question: are crops responding to P, K and S applications on their own, or in interaction with each other?

Results of these experiments suggest that P is a key element for increasing crop growth and performance. They also suggest it is a pre-requisite for crop responses to K or S (i.e. you are unlikely to get a response to K or S without adequate P being present.)

Sites in central Queensland and northern NSW also demonstrate greater uptake of N, K and S when P application is made. [35] To get an adequate response to P at depth, K is also required.

For more information, download the GRDC Update paper http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs.

More information

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Whats-new-with-zinc-maybe-just-some-critical-reminders

5.14 Current general pre-plant nutritional levels for zinc and micronutrients

Zinc deficiency occurs in some of the alkaline brigalow soils and some of the heavy, alkaline, flooded clay soils along Queensland's river systems, particularly following a long fallow. The use of Sulfonyl Urea herbicides can also cause Zn deficiency. As Zn plays an important role in the efficient uptake of N for protein, its significance should not be ignored and any suspected deficiencies should be addressed. Zinc deficiency can be corrected by applying a Zn fertiliser with the seed at planting or incorporating zinc sulfate monohydrate into the soil 2–3 months prior to planting.

Copper deficiency has occurred in a band from Wandoan through Miles, Tara, and Moonie to Goondiwindi. The area affected, however, is patchy and small.

5.15 Nutritional deficiencies

Micronutrient deficiencies can be tricky to diagnose and treat. By knowing your soil type, considering crop requirements and the season, and supporting this knowledge with diagnostic tools and strategies, effective management is possible.

Key points

- Micronutrient deficiencies are best determined by looking at the overall situation: region, soil type, season, crop and past fertiliser management.
- Soil type is useful for deducing the risk of micronutrient deficiencies.
- Tissue testing is the best way to accurately diagnose a suspected micronutrient deficiency. The correct plant part for the appropriate test must be taken (e.g youngest fully expanded leaf).
- When tissue testing, sample the appropriate tissues at the right time. Plant nutrient status varies according to the plant's age, variety and weather conditions.
- The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small.

[35] D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers 7 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs

When applying fertiliser to treat a suspected deficiency, leave a strip untreated. Either a visual response or tissue testing can allow you to confirm whether the micronutrient was limiting.

5.16 Soil testing

Before a fertiliser program can be designed, it is important to estimate the existing soil nutrient status. Continuously low grain protein levels are indicative of low soil nitrogen. When barley protein levels are below 11.5% dry or below 10–11% at 12.5% moisture, grain yield losses are likely. [36]

Soil testing regimes used today were developed when soils were potentially more fertile in the subsoil and when conventional tillage re-incorporated crop residues. Because the way we farm has changed, these testing strategies may no longer accurately predict soil fertility status, and they need to be revisited. [37]

Soil testing and professional interpretation of results should now be an integral part of all management strategies. Soil tests estimate the amount of each nutrient available to the plant rather than the total amount in the soil. Valuable information obtainable from a soil test includes current nutrient status, acidity or alkalinity (pH), soil salinity (electrical conductivity (EC), and sodicity (exchangeable sodium percentage), which can affect soil structure.

Soil test information should not be used alone to determine nutrient requirements. It should be used with test strip results, and previous crop performance and soil test records, to obtain as much information as possible about the nutrient status of a particular paddock.

It is essential that soils be sampled to the correct depth. Sampling depths of 0–10 and 10–30 cm should be used for all nutrients. Additionally, a soil test at 30–60, 60–90 and 90–120 cm (or to the bottom of the soil's effective rooting depth) is required for N, S, EC, chloride and exchangeable cations.

Care must be taken when interpreting soil test results, as nutrients can become stranded in the dry surface layer of the soil after many years of zero or reduced tillage, or deep nutrient reserves may be unavailable due to other soil factors, such as EC levels. [38]

Test strips allow you to fine-tune your fertiliser program. To gain the maximum benefit:

- Run them over a number of years, as results from any single year can be misleading.
- Obtain accurate strip weights.
- Protein test a sample of grain from each strip.
- Harvest strips before your main harvest, as the difference between the strips is more important than the moisture content.

When setting up a test strip area:

- Ensure you can accurately locate the strips.
- Repeat each fertiliser treatment two or three times.
- Change only one product rate at a time.
- Separate each strip of fertiliser by a control or nil fertiliser strip.

[36] DAFF (2012) Barley planting, nutrition and harvesting. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

[37] GRDC (2012) Crop nutrition. Northern region—phosphorus management. GRDC Fact Sheet Nov. 2012, http://www.grdc.com.au/~/media/578CC7FEE649428D9C4C90B7461537D0.pdf

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

- Keep clear of shade lines, trees, fences, headlands and any known anomalies in the field.
- Ensure that the test strip area is ~100 m long, with each strip 1–2 header widths.

Colour photographs of nutrient deficiencies can be found in: 'Hungry crops: a guide to nutrient deficiencies in field crops', by NJ Grundon (1987), Department of Primary Industries, Queensland Government Information series Q187002. [39]

5.16.1 Rules of thumb

Choose the same test package each year (including methods), otherwise comparisons between years will be useless. For example, do not use Colwell-P for P one year, then DGT-P the next. The two tests measure different forms of available P in the soil.

If you do not use a standard approach to sampling, a comparison of the data between different tests will not be reliable. Aim for data that have the best chance of representing the whole paddock, and mix the sample thoroughly.

For monitoring, sampling needs to cover roughly the same area each time to ensure comparisons between years are meaningful. Permanent markers on fence posts to mark a sampling transect or a handheld GPS will serve this purpose.

Soil testing laboratories should be able to provide information on appropriate soil sampling and sample-handling protocols for specific industries and crop types. Refer to the Australian Soil Fertility Manual (available at http://www.publish.csiro.au/pid/5338.htm). For more information, download the GRDC Fact Sheet 'Better fertiliser decisions for crop nutrition' at http://www.grdc.com.au/GRDC-FS-BFDCN. [40]

5.17 Plant and/or tissue testing for nutrition levels

Tissue testing is the best way to accurately diagnose nutrient deficiencies when a crop is growing, whether this is the macronutrients or micronutrients such as Zn and Cu (Figure 11).

The successful use of plant tissue analysis depends on sampling the correct plant part at the appropriate growth stage as demonstrated by Dang (1992; see Figure 6 therein) for Zn. Similarly, the critical tissue P concentration changes with the age of wheat plants (Elliott *et al*. 1997*a*; 1997*b*).

For these reasons, critical tissue concentrations should be associated specifically with defined stages of plant growth or plant part rather than growth periods (i.e. days from sowing). Growers are advised to follow laboratory guides or instructions for sample collection.

Plant nutrient status varies according to the plant's age, variety and weather conditions. The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small.

When applying fertiliser to treat a suspected deficiency, leave a strip untreated. Either a visual response (where a 20% yield difference cannot be seen) or plot harvesting of the strips can allow you to confirm whether the micronutrient was limiting. [41]

39 DAFF (2010) Nutrition management. Overview. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

40 GRDC (2013) Better fertilizer decisions for crop nutrition. GRDC Fact Sheet Nov. 2013, http://www.grdc.com.au/GRDC-FS-BFDCN.

41 GRDC (2013) Micronutrients and trace elements, GRDC Fact Sheet 2013. http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients

More information

GRDC Podcast:
http://www.grdc.com.au/Media-Centre/GRDC-Podcasts/Driving-Agronomy-Podcasts/2010/06/Plant-Tissue-Testing-uncovering-hidden-hunger

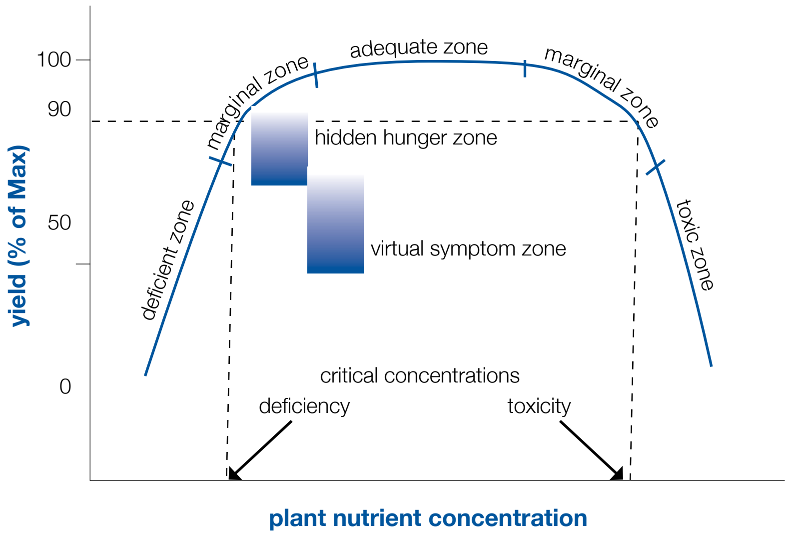

Figure 11: Generalised grain-yield response curve

5.18 Nutrition effects on the following crop

In consultation with regional agronomists and crop consultants, typical 5-crop rotation sequences were developed for each of the regional production environments in the northern grains region. The accumulated deficits or surpluses of N, P and K over this crop sequence (the period will depend on rainfall) are shown in Table 8 based on a summation of the individual deficits or surpluses from the crops in the database. While this approach has limitations (especially in regions where the majority of crops monitored were drought-affected), it serves to highlight the extent of nutrient depletion that is occurring. Not only in risky dryland environments such as the Central Highlands, but also in more reliable, generally higher input systems such as the Eastern Downs and Liverpool Plains. If this depletion continues unchecked, there will be long-term consequences for the sustainability of the soils supporting the northern grains farming systems.

Table 8: Typical rotation sequences in the various production regions and the surpluses or deficits of N, P and K (kg/ha) over this sequence of five crops. Chickpeas assumed to have net N balance of zero (addition = removal)

Region	Crop sequence (5 crops)	N : P : K (kg/ha)
Central Highlands	Sorghum, sorghum, sorghum, wheat, wheat or Sorghum, sorghum, wheat, chickpea, wheat	–262, –3, –41 –202, 1, –47
Dawson Callide	Chickpea, sorghum, wheat, mungbean, wheat	–59, –14, –63
Eastern Downs	Sorghum, sorghum, short fallow, wheat, long fallow, sorghum, sorghum	–245, –48, –91
Goondiwindi-Moonie	Wheat, chickpea, wheat, long fallow, sorghum, sorghum	–115, –5, –61
Liverpool Plains	Wheat, barley, long fallow, sorghum, sorghum, sorghum	–116, –62, –109
Moree-Narrabri[A]	Wheat, fallow, sorghum, wheat, fallow, sorghum, wheat or Wheat, fallow, sorghum, wheat, chickpeas, fallow, sorghum	–60, 7, –34 –40, 10, –23
NorthStar	Wheat, chickpea, wheat, long fallow, sorghum, sorghum or Barley, Chickpea, Wheat, long fallow, sorghum	–115, –5, –61 33, 5,: –6
South Burnett	Peanut, maize, peanut, sorghum, wheat	Insufficient info.
Western Downs	Wheat, wheat, wheat, sorghum, sorghum	–74, –8, –20

[A] Durum wheat is typically grown in Moree–Narrabri crop sequences, but wheat was substituted in these calculations due to no available nutrient removal data for durums.

In order to put a current costing on the depletion of these soil reserves, or alternatively a nutrient replacement cost of meeting these deficits with fertilisers, calculations were made using fertiliser prices in November 2008 to manage macronutrients only (i.e. N, P, K and S). In these calculations (based on individual crops) it was assumed that where P deficits occurred, that deficit would be met by applying additional mono-ammonium phosphate. This would obviously also supply some N, which would reduce the cost of any additional N inputs (costed as urea). In a similar fashion, S deficits were costed based on applying sulfate of potash fertiliser, with the K applied in this product reducing the amount of K that needed to be applied as muriate of potash. The cost of each nutrient at that time was as follows: P as mono-ammonium phosphate ($8.80/kg), N as urea ($2.92/kg), S as sulfate of potash ($11.12/kg) and K as muriate of potash ($2.55/kg). In situations where a surplus of nutrient had occurred (e.g. in the case of P in some crops), a credit was generated equivalent to the amount of that nutrient in order to reduce the cost of overall nutrient decline. Data are shown in Figure 12.

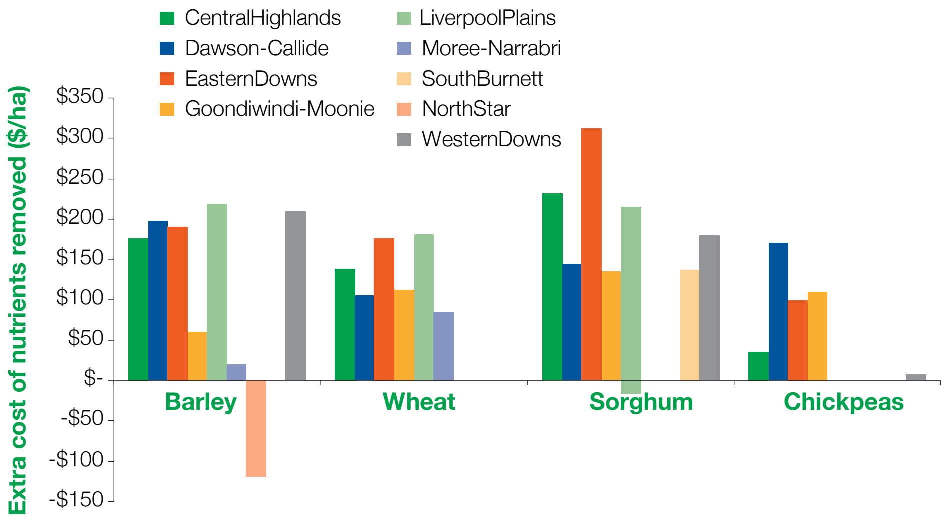

Figure 12: Estimated AU$ value of fertiliser needed to replace nutrients exported from soils across the northern grains region in the study period.

Results clearly show the significant cost of nutrient depletion that will need to be met by future grain-producing systems at some stage. The average additional cost per ha of replacing these nutrients was $106 for barley, $89 for wheat, $153 for sorghum and $47 for chickpea, with these costs often doubled in the higher production regions. The anomaly for barley in the North Star area (and probably the low deficits for Moree–Narrabri and Goondiwindi-Moonie in some cases) will be addressed by addition of better production years to the database. If growers are to meet these costs, they will need to see some combination of higher grain prices and lower fertiliser prices, and adopt efficient nutrient application strategies to continue to be viable and sustainable. [42]

5.19 Paddock nutrition

Monitoring crop yields and protein over time can give a good indication of the N status of a paddock (Table 9).

[42] M. Bell Soil characteristics and nutrient budgeting in northern grains region.

Table 9: Using grain protein of preceding barley and wheat crops as an indicator of paddock nitrogen status

Barley protein (dry basis) (%)	Wheat protein (11% moisture) %	Comments
<8.5	<10	Acutely N deficient. Potential yield loss may be in excess of 30%. Applied N should increase yield significantly. Grain protein would be increased only if a large amount of N was applied
8.5–11	10–11.5	Moderately to slightly N deficient. At least 15% yield loss is likely because of low soil N. Yield would probably be increased by applying N if there were no other limiting factors (e.g. soil moisture)
11–12	11.5–12.5	Satisfactory N status for optimum yield. Additional N would probably not increase yield but would be likely to increase grain protein
>12	>12.5	Nitrogen not deficient. Yield was most likely limited by water deficit. Additional N would not increase yield but would probably increase grain protein. If high protein and low yield occur, even in years of good rain, P may be deficient

Source: Department of Agriculture, Fisheries and Forestry, Queensland.

Harder to evaluate is a paddock's SOM, an under-valued capital resource that needs informed management. Traditional cropping practices have dramatically reduced SOM levels, which, with related nutrients, are of much more value than soil carbon itself.