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Government of Western Australia
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GRDC
Grains Research & Development Corporation

Wheat CRC

SEPWA

Contents

1. Introduction

This manual is part of a joint project between the Department of Agriculture and Food WA and the South East Premium Wheat Growers Association (SEPWA) with funding from the Grains Research and Development Corporation (GRDC). Growers in the Esperance port zone have been concerned with declining protein levels in wheat and its impact on farm returns as well as strong messages from processors of Esperance wheat that they require higher protein in the wheat they mill and process.

The project entailed grower involvement in designing and executing field scale experiments using farmer machinery, grower workshops, field days and meetings to learn about nitrogen dynamics in farming systems and using fertiliser to manage wheat protein and yield.

I acknowledge the assistance of many growers who conducted experiments, arranged meetings and commented on the results of the field investigations as well as this manual. Department staff were also involved as technical officers, Penny Malone, Terina Burnett, and Colin Boyd, joint project supervisor Ben Curtis and Bill Bowden for mentoring with nitrogen nutrition expertise.

2. Why worry about protein?

Grain protein is one of the parameters of grain quality. Grain protein in the range appropriate for the various end uses of wheat is critical for making acceptable quality products such as bread, various types of noodles and biscuits. Protein ranges are set for premium grades of wheat and barley. Grain outside the specified ranges is downgraded to a lower paying grade, even as low as feed. Indications are that in future low protein grain will be increasingly difficult to sell leading to a greater differential between premium and feed grain prices. Figure 2.1 shows the effect of protein level on grain price for the grades most growers target in the Esperance port zone. The protein payments are reviewed frequently and the rate of protein payment and levels at which protein payment rates alter, change

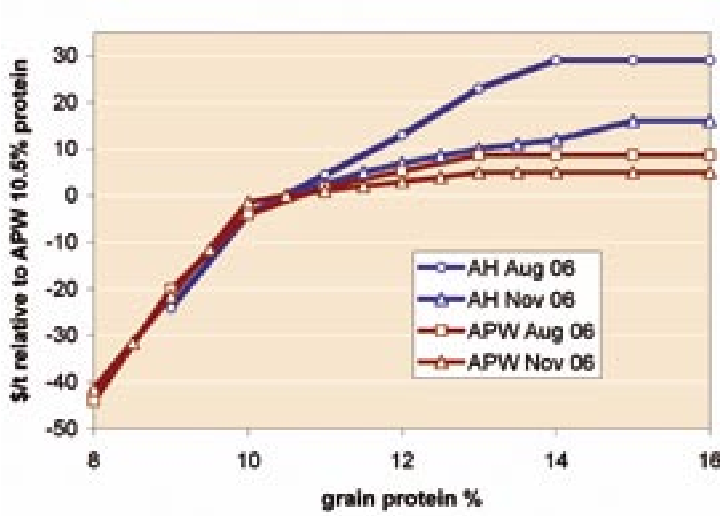


Figure 2.1: GOLDEN REWARDS® protein payments as at August and November 2006 for wheat protein within AH and APW and grades. FOB values assume standard screenings and moisture for all grades. Prices are relative to APW 10.5 per cent protein and AH 11.5 per cent protein.

frequently according to market conditions. Premiums and discounts are generally higher for AH and APW grades than ASW. Discounts below 10 per cent protein are always greater than premiums for levels of protein higher than 10 per cent. This means that lifting protein from levels lower than 10 per cent is usually economic as this is the protein range with the highest protein pay increment and where nitrogen increases yield as well as protein. (see section 3)

Over recent years, despite variation in protein with seasonal conditions and yields, the average wheat protein in the Esperance Port Zone has generally declined. Many growers feel they would get better returns if they could produce reliably higher protein grain. With increasing crop yields and fewer legume years in cropping rotations, crop requirement for fertiliser nitrogen has increased. In good seasons the increased crop demand has not been met with higher fertiliser applications.

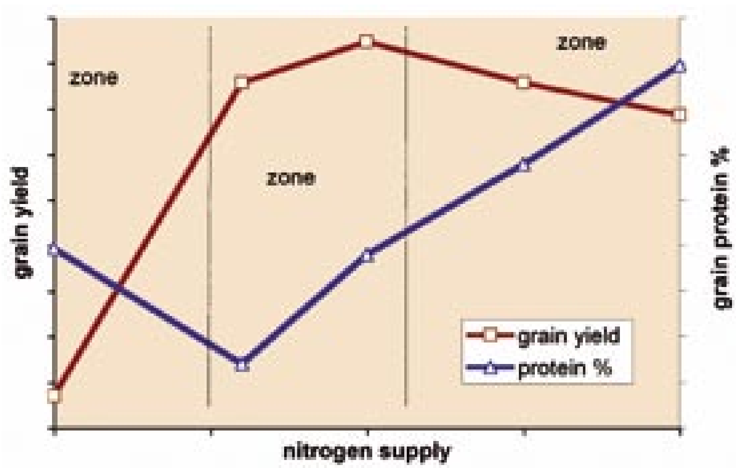


Figure 3.1: The generalised relationship between nitrogen supply, crop grain yield and grain protein content. Derived from a field experiment at Salmon Gums in 2004.

3. The relationship between nitrogen supply, protein and yield

There is a direct relationship between nitrogen supply from all sources, grain yield and grain protein content. This is illustrated by figure 3.1 showing three main areas of nitrogen supply. A paddock can be in any of the N supply zones depending on soil nitrogen status and potential yield according to the season in question. In zone 1 of extreme deficiency, additional nitrogen supply will increase yields markedly. It is likely that 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 per cent.

As nitrogen supply increases to moderate levels (zone 2 in diagram 3.1), both crop yields and protein are increased with additional N fertiliser. Crop yields are 60-80 per cent of potential but grain protein is still below 10 per cent. As nitrogen becomes adequate to excessive as in zone 3, crop yields are near potential or declining from excessive nitrogen and unlikely to respond to extra nitrogen, but grain protein increases in response to extra N applied. Generally the efficiency of N recovery to grain decreases as N supply increases.

4. Other influences on grain protein

Grain protein is influenced by several factors, some of which can be managed by the farmer. Figure 4.1 illustrates the relative influence of many factors which effect grain protein. Potential yield as determined by rainfall is the largest factor. Potential yield influences the relative supply of N in relation to the grain yield. High yield from good seasonal rain and prolonged cool moist grain filling conditions has the effect of diluting the protein laid down early in grain development. Short maturation period with hot and dry conditions during grain filling limit the amount of starch accumulated in the grain effectively increasing the protein content and decreasing grain size at the same time.

There is a fine balance between nitrogen supply and water available for crop growth and production. This makes nitrogen decisions difficult as fertiliser needs to be applied before grain fill, well before the end of the season. Generally, the latest effective time for nitrogen fertiliser is flag leaf emergence to booting.

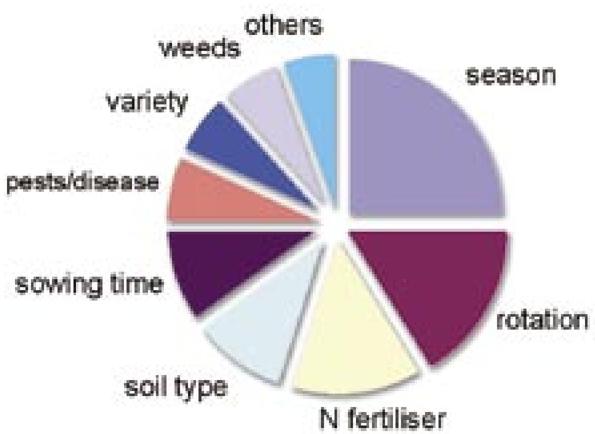


Figure 4.1: Relative influence of factors effecting grain protein. (After W Anderson unpublished)

Late sowing increases grain protein by reducing yield through a shortened grain filling period.

Weeds usually decrease protein. Weeds compete with crop for nitrogen uptake, reducing nitrogen available to the crop. Diseases can influence protein either way, depending on how the disease effects growth and development. Leaf diseases such as mildew and rust reduce yield potential. Powdery mildew in barley reduces tiller number and yield and can increase protein levels. Leaf rust in wheat frequently reduces both yield and protein. Take-all reduces root growth, yield and nitrogen uptake. Reduced nitrogen uptake and reduced yield means that there is no consistent effect on protein

Other nutrient deficiencies usually reduce crop yields and increase protein. An example of this is potassium deficiency where nitrogen applied alone can have little effect on yield and protein but when applied with potassium increases yield and dilutes protein. Trace element deficiencies usually reduce yield with the effect of increasing protein – this is normal for most interacting nutrients.

Ripping light soils can increase yield AND protein because it increases N uptake efficiency by better and more rapid root penetration to depth, allowing plants to capture nitrogen that would otherwise be beyond the root zone.

Soil type influences grain protein by nitrogen dynamics and soil moisture supply. Heavier soils usually have higher organic matter than sandy soils because they have more ‘protected sites’ for organic matter. Heavier soils store more water for a given depth and are less likely to loose mineral nitrogen from leaching. In drier regions water seldom moves below the cereal root zone in normal seasons. Mineral nitrogen can accumulate under shallow rooted pasture and pulse phases to be 'harvested' by deeper rooted cereals in following years. With restricting layers in subsoils such as transient salinity, boron salts or extreme bulk density, nitrogen can accumulate below the effective cereal root zone, even at shallow depths. Crops may not respond to pasture, pulse or green manure years if the nitrogen moves into inaccessible layers with heavy summer rainfall. Light well drained soils can result in leaching of nitrate beyond the root zone – particularly early in the season and this can result in a lower yield potential. If the crop grows into the relatively N rich moisture at depth late in the season then surprisingly high proteins can result.

Frost reduces grain numbers and yield, consequently protein is generally higher in frosted crops.

Within a wheat class, variety has little influence on protein at equivalent yield. Any apparent changes in protein content are largely due to yield differences – higher yield leading to lower protein. Hard varieties usually have 0.5 per cent higher protein than ASW and noodle varieties which in turn have slightly higher protein than soft varieties. In barley, the more recent high yielding malt varieties like Gairdner⊕ and Baudin⊕ have lower grain protein than other varieties at high yields. Gairdner⊕ is known to be less efficient in transferring N from the plant into grain than other varieties.

5. Paddock variation in grain protein

Grain protein varies between paddocks and seasons as discussed in other sections of this manual but also within paddocks. Intensive paddock monitoring at Merredin in the early 1960s showed large variation in grain protein within a paddock due to soil type variation and other less obvious factors. Parish (1963) showed ranges of wheat grain protein within harvester runs from 7.25 to 15.7 per cent grain protein and average protein between consecutive runs of 12.9 to 13.6 per cent. Grid samples collected by hand across the same paddock ranged from 6.9 to 17.1 per cent protein in a paddock which averaged 12.9 per cent. Grain protein measurement is an averaging process with correct sampling procedure required to get meaningful results.

Paddock zoning as in Precision Agriculture is defining both yield and protein variation within paddocks and the potential for managing zones within paddocks to better target paddock inputs, especially nitrogen fertiliser.

6. How we used to grow high protein wheat

In the past, high protein wheat was relatively common. Rotations were longer with several pasture years for each crop year. Nitrogen fixed in pasture swards is proportional to the amount of dry matter grown, the legume percentage of that dry matter and the number of years of the pasture phase. Nitrogen accumulates as both plant residue organic matter and as soil organic matter. Fig 6.1 illustrates this accumulation of nitrogen and its subsequent depletion through a cropping cycle. By looking at the accumulation of nitrogen in a 2 pasture:1 cereal rotation there is often an excess of nitrogen fixed compared to export in grain. Coupled with lower crop yields from later sowing and old cropping systems there was often excessive nitrogen for the grain yield resulting in high grain protein levels. They also cropped heavier soils and they also used fallow in the 'good old days'.

Mostly, crop nitrogen requirements were derived from legume and soil organic matter which is released throughout the growing season ensuring a supply of nitrogen through flowering and grainfill if the surface soil remains moist.

In current farming systems, several non-cereal crops are grown in succession, depleting the limited legume residue organic matter from the few legume years. Higher yields from adapted varieties, earlier sowing and better weed and disease control contribute to the decline in protein levels unless nitrogen supply is maintained with increasing rates of fertiliser nitrogen. Predicting yield and protein response early enough in the season to apply an effective and economic rate of fertiliser nitrogen is challenging.

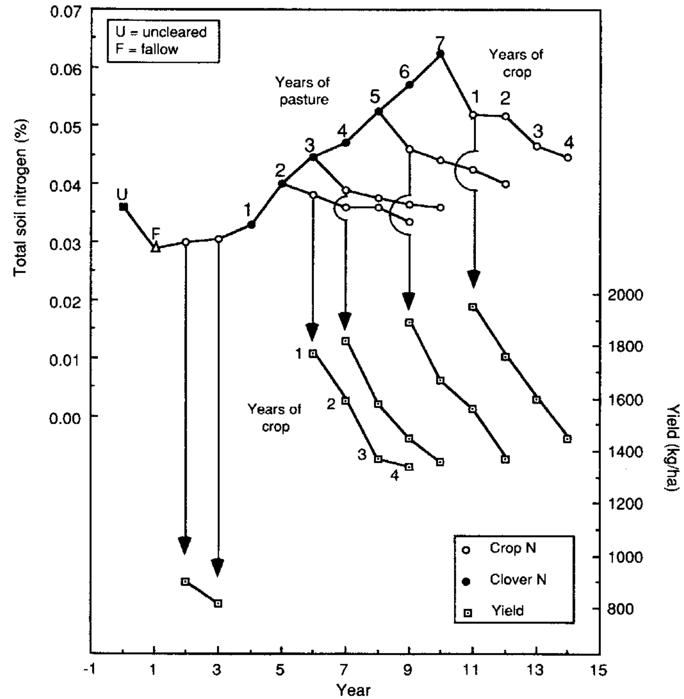


Figure 6.1: Nitrogen accumulates under pasture and declines under non-legume crops.(source: The Wheat Book p. 114)

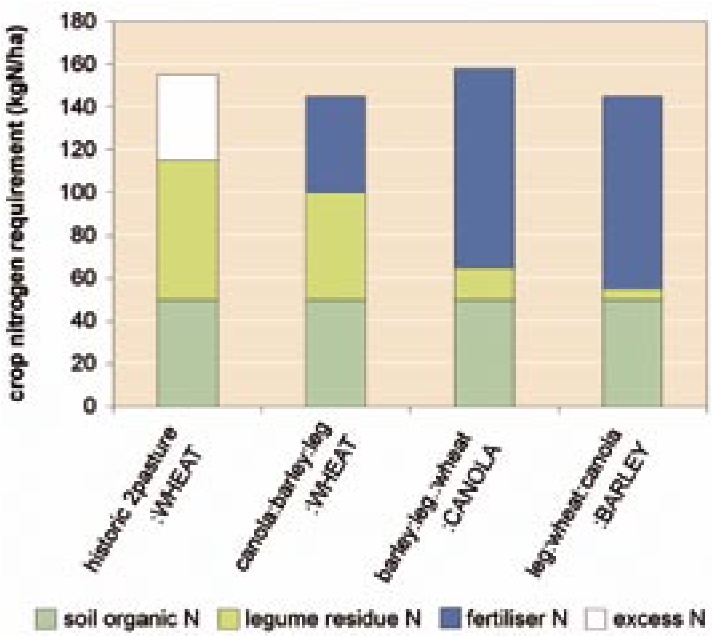


Figure 6.2: Increasing proportion of crop nitrogen fertiliser requirement with time from legume year. Derived from SYN for modelled yield and protein

Figure 6.2 illustrates the increasing reliance on fertiliser nitrogen for crop production. The nitrogen requirement for each year in a rotation of legume crop, wheat, canola and barley is compared to nitrogen in a 2 pasture:1 wheat rotation. The assumptions are that the soil has 1 per cent organic carbon with no mineralising summer rain, the historic wheat yielded 2 t/ha with 12 per cent grain protein. The newer rotation has a legume crop yielding 1 t/ha, wheat and barley yielding 3 t/ha with 10 per cent protein and canola yields 1.5 t/ha with 42 per cent oil. Figure 6.2 also illustrates the declining contribution of legume residue nitrogen through time.

In many farming systems, a one year pulse crop has substituted for the long pasture phases of the past. The contribution of pulses to nitrogen for following crops is dependent on the total biomass yield of that legume crop and the proportion of that yield removed as grain as illustrated in figure 6.3. High biomass crops with low yield contribute relatively larger amounts of nitrogen to following crops such as the large, leafy, low yielding sandplain lupin crops of the 1980s and frosted pea crops. Conversely poorly grown lupin and pulse crops (short, low biomass) that yield well contribute little nitrogen in low rainfall areas in some seasons.

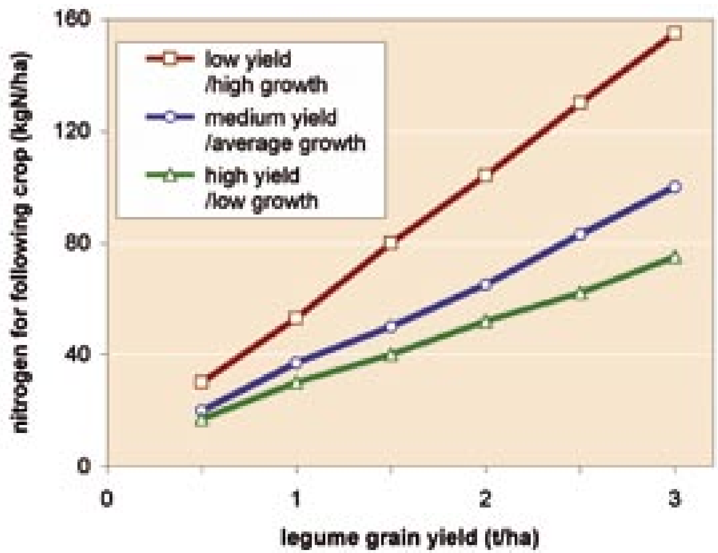


Figure 6.3: Influence of relative legume crop yield to crop growth on nitrogen contribution to following non-cereal crop. (derived from Nitrogen Calculator)

7. Organic matter - a constant base

Soil organic matter (as distinct from legume residue organic matter) is a significant source of nitrogen for any crop. Plant residues, both tops and roots decompose over several years to become soil organic matter. A wide range of soil organisms obtain their energy and most of their nutrient requirements by breaking down plant (and animal) materials. In the process as much as 70 per cent of the carbon in the fresh material is respired as carbon dioxide in the first year. Only 30 per cent of the carbon in fresh organic matter remains in soil organic matter which is further broken down in following years. In many pasture:crop systems, the nitrogen from soil organic matter is the largest source of nitrogen for cereal crops. While plant residues are being broken down to form soil organic matter, the soil organic matter itself is being cycled to release many nutrients, of which nitrogen is the main one.

Climate, soil properties, and paddock management influence the soil organic matter balance by changing the amount of plant material grown, its return to the soil and the decomposition rates of the plant residues and soil organic matter.

The most common method of estimating soil organic matter in Australia is the Walkley-Black technique measuring Organic Carbon percentage (OC%). It is expressed as percentage of the (< 2 mm) soil mass - the sample most commonly collected is cores from the top 10 cm of the soil profile. A range of factors can be used to convert Organic Carbon to Organic Matter, these range from 2.0 to 2.4, that is OC% x factor = Organic Matter %

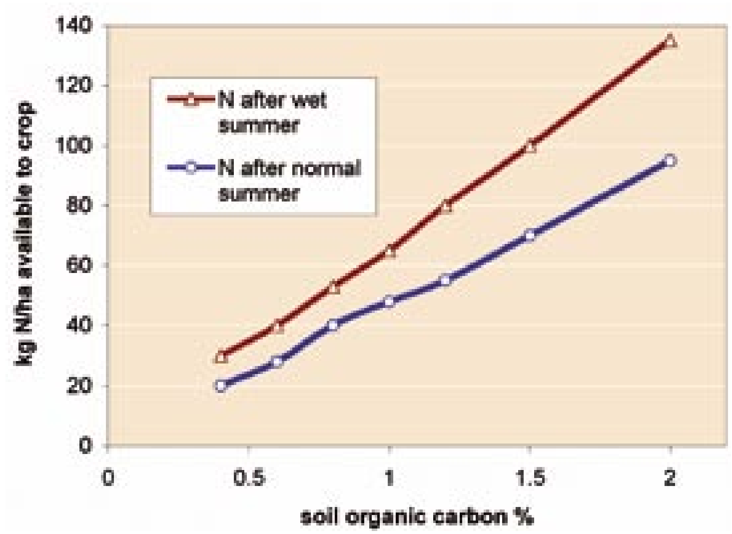


Figure 7.1: Expected crop nitrogen supply from soil organic matter and influence of summer rainfall.

Each year a proportion of the organic matter breaks down releasing nitrogen - a rule of thumb is 3 per cent of the soil organic matter breaks down releasing nitrogen but this is dependent on soil temperature and duration of suitably moist conditions for microbial activity. Significant summer rainfall (during warm weather) increases the amount of N released from organic matter as illustrated in figure 7.1.

8. Nitrogen sources and their features

There are many sources of nitrogen contributing to crop growth, each with attributes that influence its availability during the crop growth cycle.

Soil organic nitrogen

This is derived from the decomposition of soil organic matter, which is often referred to as humus, through soil organisms using it as a food source. It is a form of slow release nitrogen which can match the crop demand for nitrogen especially in warm, moist spring conditions. If there is good spring rain, the microbial activity in warm moist soils mineralises nitrogen at a time when crop demand increases with increasing yield potential. Soil organic matter can also release nitrogen at inappropriate times such as after summer rain. This summer release of mineral nitrogen can be lost through leaching on sandy soils and with excessive rainfall before the crop roots are deep enough to take the nitrogen up.

Plant residue nitrogen

The amount of nitrogen available from plant residues is related to the carbon to nitrogen (C:N) ratio of the residue. Residues need to have a C:N ratio lower than about 27 to release mineral N available for a crop. Fine legume materials such as leaves, pods and freshly killed seedlings are a good source of nitrogen from such residues. Cereal straw, lupin stems and roots all have a high C:N ratio, not releasing any nitrogen when they initially decompose. If such high C:N materials are incorporated in the soil they tie up or immobilise nitrogen as the organisms feeding on the material need a higher proportion of nitrogen than the residue is supplying. In time, as carbon dioxide is respired, the products of decomposition approach a C:N ratio that is able to provide a net release of nitrogen through mineralisation of these products.

Urea fertiliser

Urea is the most commonly used nitrogen fertiliser in our area due to its relative price advantage over other nitrogen fertilisers and its high nitrogen content, giving freight advantages compared with less concentrated fertilisers.

Urea has potential disadvantages. It can not be drilled in the seed row at rates higher than about 20 kg/ha at 17 cm row spacing due to seedling toxicity. However, it can be banded away from the seed either below or to the side with negligible risk. Urea spread on the soil surface can be lost by volatilisation under dry conditions, especially on alkaline soils. Losses up to 40 per cent have been measured under extreme conditions of a moist soil surface, warm temperatures and no following rain. Volatilisation losses can be minimised by burying urea deeper than about 2 cm, even in dry soils. Within a few days of contact with soil, urea is transformed to ammonia which dissolves in soil moisture to form the ammonium ion which is further changed to nitrate by the action of soil microbes. In these days of stubble retention, you can get a lot more N immobilisation when nitrogen fertiliser is top dressed than when drilled and so banding and concentrating urea away from the seed can be more effective than topdressing.

Ammonium fertilisers

Compound nitrogen and phosphorus fertilisers, ammonium nitrate, Calcium Ammonium Nitrate (CAN) and Sulphate of Ammonia contain the ammonium form of nitrogen. Ammonium is a positively charged ion and is weakly held on Cation Exchange sites in the soil. It is not readily leached from the topsoil until it is changed to the negatively charged nitrate ion. It is possible for ammonium such as from ammonium sulphate to be lost through volatilisation on alkaline soils to a similar degree as urea.

Ammonium ions can be taken up by plants. Plants taking up ammonium excrete an acid ion to maintain electrical balance of the cells. Take-all infection of cereal roots can be reduced by such an acidified root surface.

Nitrate fertilisers

Most ammonium nitrogen in the soil is rapidly transformed to nitrate which is readily taken up by plants. Nitrate is prone to leaching. It is a negatively charged ion which is not held by the cation exchange sites in soil. Nitrate can be transformed into nitrogen and nitrogen oxide gases under waterlogged conditions in the presence of microbes and organic matter, another potential loss of nitrogen from the soil. Nitrate is not subject to volatilisation losses - CAN is reputed to be more effective as a post sowing top-dressed nitrogen source for cropping than urea. This was demonstrated at two out of three experiment sites in 2003. At the third site in 2003 there was no difference between CAN and urea. The principle here is that as a negatively charged ion, nitrate can move into the effective root zone while the ammonium stays in the drier surface. Ammonia volatilisation would only be a problem on high pH soils.

The only commonly used sources of nitrate as fertiliser in broad scale agriculture in the Esperance port zone are CAN with 50 per cent of the N content in nitrate form and Urea Ammonium Nitrate - UAN with 21 per cent of the nitrogen content as nitrate.

Liquid N fertilisers

There is increasing interest in liquid nitrogen fertiliser as crops in intensive cropping systems are supplied a higher proportion of their nitrogen requirements from fertiliser. Urea Ammonium Nitrate - UAN (such as Flexi-N® and Summit UAN) offers flexibility in nitrogen fertiliser management. It is a solution of half urea and half ammonium nitrate with attributes of both products. While there is some direct leaf uptake of these dissolved forms of nitrogen (about 10 per cent of that applied) most of the fertiliser has to wash off the leaves and into the soil in a similar manner to solid fertilisers. The main efficiency of UAN is the ability to apply nitrogen at the same time as other spraying operations and the ability to apply product evenly and handle it in wet conditions. Several smaller doses can be applied, matching the applications to crop demand both by time and total amount while reducing the risk of loss from leaching or from waterlogged soils.

There is little evidence to suggest that liquid nitrogen fertilisers are any more effective than solid fertilisers. It is possible that under dry conditions, as can happen later in the season, you do not get uptake from the soil, but can get limited foliar uptake. At this timing there is a risk of leaf burning which can reduce final green leaf area and reduce yield.

9. Plant demand for nitrogen and timing of application

Plants require nitrogen for protein synthesis and growth. The amount of N required is proportional to the biomass of crop grown, the growth stage and the target protein content of the grain. The demand per unit of crop biomass falls with time because the amount of low nitrogen structural tissue increases as a proportion of total biomass. The nitrogen uptake of cereals increases steadily with time during crop growth compared to the biomass accumulation which is 'S shaped'. Figure 9.1 illustrates the slow initial growth of crop, followed by a period of rapid growth in spring, then slower accumulation of weight as the crop matures under warming and drying conditions. There is a relatively high uptake of nitrogen for the amount of crop growth in the early stages of growth. Tissue concentrations of nitrogen decline with development. While common practice is to apply all the fertiliser nitrogen at sowing or within a few weeks of sowing, nitrogen can be applied later if there is a good chance that rainfall after application will wash the fertiliser into the active root zone. Delayed applications are required in leaching high rainfall environments, waterlogging paddocks and seasons with excellent spring growing conditions where crops are developing well beyond the target yield for which initial nitrogen fertiliser rates were set.

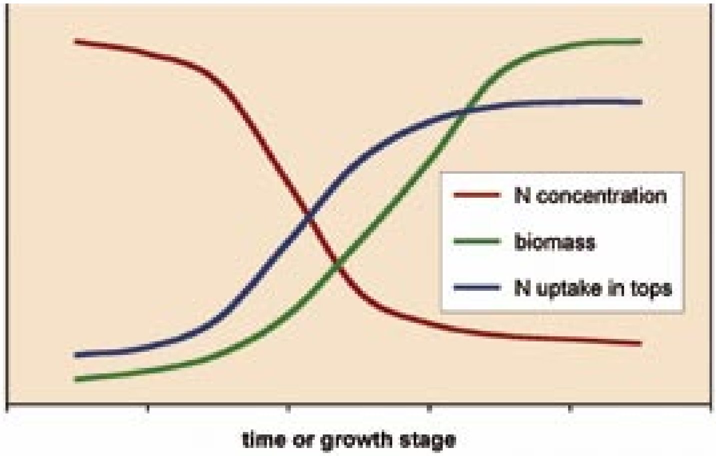


Figure 9.1:Generalised changes in cereal tissue nitrogen concentration, crop biomass and nitrogen uptake through the growing season

A concern with supplying nitrogen fertiliser to a crop is the timing of post sowing applications in relation to the plant availability of that application. Fertilisers applied to the soil surface need to be dissolved by rain and carried into the crop root zone. On heavier soils in lower rainfall environments the chance of effective post sowing fertiliser application is lower than high rainfall areas, hence the standard recommendation that all nitrogen should be applied at sowing time in low rainfall areas. High levels of nitrogen during tiller and head formation will set up a high yield potential through head and grain numbers. By flowering, generally, cereals have taken up most of their nitrogen requirement. Nitrogen is then redistributed within the plant after flowering for deposition of protein in grain. In good season finishes with late rain, nitrogen fertiliser applied late can be taken up by crop roots, increasing grain protein. Similarly, nitrogen uptake continues late in the season if continuing root growth catches up with earlier nitrogen leached to depth and the crop draws on stored soil moisture.

Canopy management

The aim of canopy management is to delay nitrogen application until there is plant demand for nitrogen. Early nitrogen stimulates high tiller numbers, many of which die off during stem elongation. Early nitrogen also stimulates a large leaf area which uses more water than a thinner canopy and can lead to early droughting of the crop and higher screenings. Leafy crops are also more prone to leaf diseases like mildew and septoria. Delayed application of nitrogen fertiliser reduces these problems while giving the same or better yield and higher protein levels than sowing and tillering application at the same rates of N. The whole question of controlling early vigour is a balancing act – with a good finish early vigour pays, with a poor finish early vigour leads to haying off. The probability of good and poor finishes varies with rainfall and growing season zone and soil type.

An experiment at Esperance Downs Research Station in 2004, illustrated in figures 9.2 to 9.5, showed no difference in grain yield from booting urea application compared to urea applied at tillering. The increased yield from booting nitrogen came from increased grain weight rather than grain numbers. The booting application also had higher protein with less screenings for the higher rates of nitrogen fertiliser.

Many experiments have shown later nitrogen application to be at least equivalent to, and in wet finish seasons, to give higher yield and protein than tillering or sowing application. In dry season finishes, late stem elongation nitrogen has caused less yield loss and screenings than tillering applications.

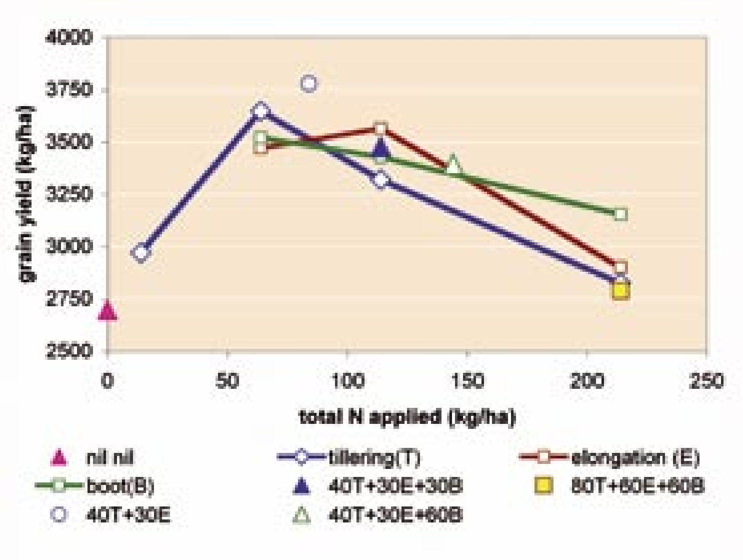


Figure 9.2: Wheat grain yield from various rates and times of nitrogen fertiliser applied as urea at Esperance in 2004

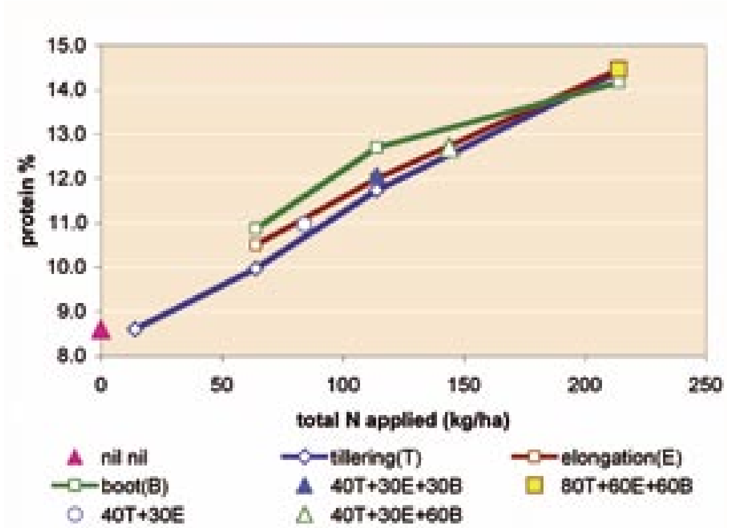


Figure 9.3: Wheat grain protein from various rates and times of nitrogen fertiliser applied as urea at Esperance in 2004

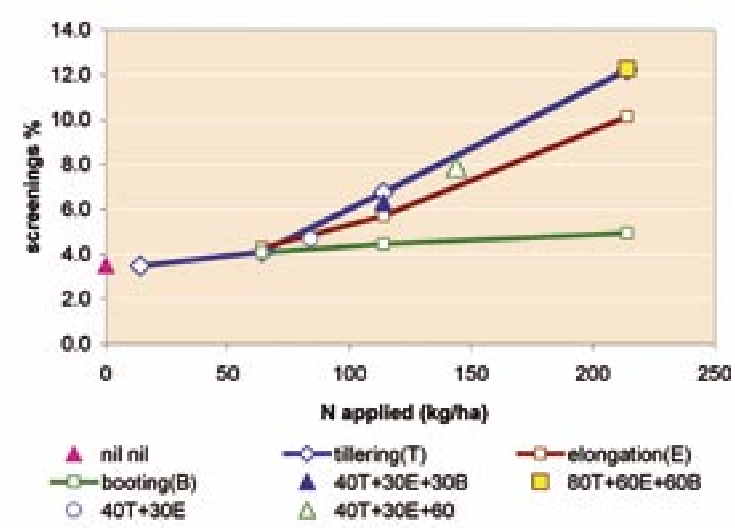


Figure 9.4: Wheat grain screenings from various rates and times of nitrogen fertiliser applied as urea at Esperance in 2004

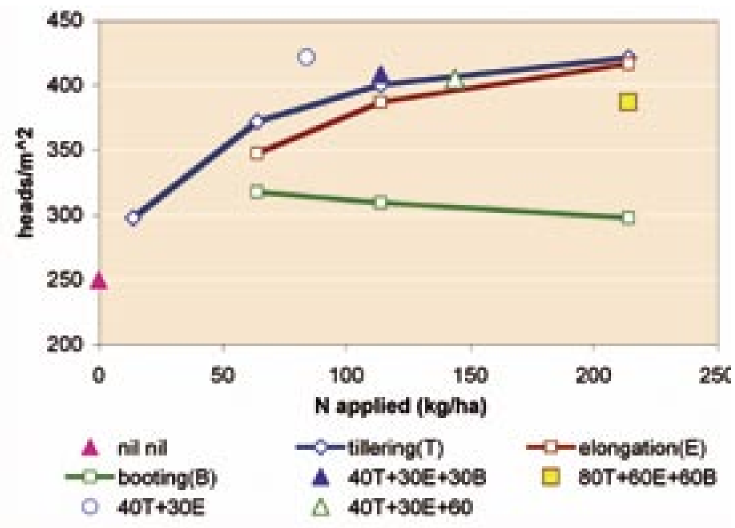


Figure 9.5: Wheat head density from various rates and times of nitrogen fertiliser applied as urea at Esperance in 2004

10. Matching nitrogen to yield potential and protein targets

By estimating an expected yield and protein content, together with nitrogen uptake efficiency, crop nitrogen demand can be calculated. It is difficult to get these estimates right at the beginning of the season. Rules of thumb are that N uptake is about 50 per cent of the fertiliser N applied and 75 per cent of the N taken up by the crop is transferred to the grain protein. As nitrogen supply increases, the efficiency of converting fertiliser N to grain protein decreases so fertilising for high grain protein requires increasing rates of fertiliser for each per cent increase in grain protein targeted.

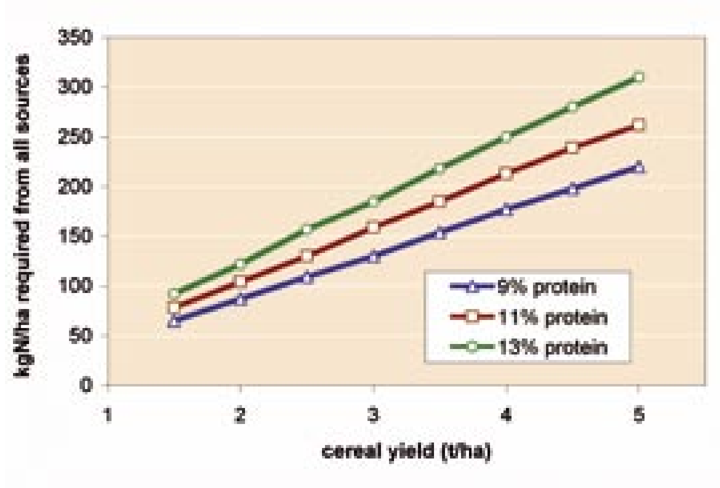


Figure 10.1: The amount of nitrogen required from all sources (soil, legume residues and fertiliser) to achieve a grain yield at a range of protein levels. (derived from Nitrogen Calculator)

Models such as SYN estimate the yield and protein response, together with expected margins to applied nitrogen fertiliser with a given paddock history, rainfall sequence and soil properties. As with many models an estimate of potential crop yield needs to be used to set the parameters for calculations.

Figure 10.1 shows the increasing amount of nitrogen required to achieve higher protein as yield increases. It also shows the amount of nitrogen required by the crop to lift protein at a given yield. The key point is to optimise economic returns for each situation which is only calculated in some models.

11. Estimating potential yield

There are many ways to estimate the potential yield when assessing nitrogen requirement of a crop. The simplest way is to use past averages. The weakness of this method is that every season is different – a good season in a low rainfall area approaches an average season in a higher rainfall zone. April to October rainfall in 2003 at Salmon Gums was 341 mm compared to the median rainfall at Esperance Downs Research Station of 360 mm. To respond to seasonal conditions, yield potential for nitrogen budgeting needs to be adjusted as the season progresses and nitrogen applied or withheld according to yield prospects at the time.

Water use efficiency.

There are many variations to calculate potential yield using the technique developed by French and Schultz. They all revolve around a factor of kilograms of grain produced for every millimetre of rain above an allowance for losses such as evaporation. One system is the Potential Yield CALculator (PYCAL), a computer based program that uses daily rainfall records for any station together with rainfall deciles and meteorological averages for regions of Australia. The program estimates stored soil moisture at sowing, adds rainfall during the growing season to date and generates an expected range of yield potential deciles from a rainfall decile table for the selected location. This can be updated as the season progresses and potential yields for crop input decisions selected according to risk preference. PYCAL estimates potential yield if all conditions are right for crop growth. It does not account for deep drainage or poor nutrition including low nitrogen. With experience in any location, model parameters for each crop can be modified to better reflect historical performance and the value of yield prediction.

Yield Prophet®

Yield Prophet® is a web based daily time-step crop growth simulation model based on the Agricultural Production Simulation (APSIM) model. Subscribers need to characterise the soil for the paddocks they are forecasting. This means sampling soil to the maximum crop root depth and analysing for mineral nitrogen, pH and electrical conductivity. A 0-10 cm sample is collected for organic carbon. Estimates of plant available water and bulk density together with sowing date, variety and nitrogen fertiliser are submitted through the web service to generate probability curves of yield and protein. Yield Prophet® generates forecasts for a specific paddock and initial conditions as measured during April. It does not estimate maximum potential yield except by generating reports with high rates of nitrogen applied.

Outputs are presented as probability curves summarising the results of up to 100 years of simulation runs using historical weather data from a nearby weather station. Outputs include grain yield, grain protein and margin to fertiliser with many other features in various reports. Reports can be generated anytime from before sowing to after crop maturity.

12. Economics of nitrogen fertiliser

The economics of nitrogen fertiliser depend on many factors. Crop yield responsiveness as determined by initial paddock fertility and potential yield are the main factors with protein payments such as GOLDEN REWARDS™ payments a secondary consideration. The biggest returns from fertiliser are gained from increasing yield rather than protein. Once a grain protein level of about 10 -10.5 per cent has been reached, further nitrogen fertiliser will only increase protein levels. In the APW and AH grades, protein increments are not sufficient to pay for the fertiliser used to increase protein to higher levels.

The difficulty is choosing a yield to base fertiliser rates on. What happens if there is too much fertiliser applied for the season or too little for the yield potential?

In the situation of too much N for the potential yield, protein levels are increased and often screenings increase at the same time. This was demonstrated in many experiments in 2004 where yields were decreased, and returns from additional nitrogen fertiliser were negative. The 2004 season was characterised by an average seasonal rainfall until mid September and almost no rain during the grain fill period.

At the other end of the spectrum too little nitrogen is applied for the yield potential. The 2003 season illustrates this when protein levels were low at 8-9 per cent with base levels of nitrogen fertiliser. Additional nitrogen fertiliser increased yields and protein with no influence on screenings. Moderate rates of nitrogen fertiliser increased returns.

The interaction of potential yield and nitrogen fertiliser rate on returns is illustrated in tables derived from SYN using 2005 on farm wheat returns of $150/t, fertiliser cost of $1/kg of nitrogen and 2004-05 protein payments

Table 12.1: Influence of potential yield and nitrogen fertiliser rates on expected yield, protein and margin of wheat in an Esperance sandplain situation. 2005 on farm prices of APW $150/t and $450/t urea. This example is based on a simulation of a crop following one canola crop after pasture for several years on a sand over gravel soil with an OC of 1.4 per cent.

	2 t/ha potential			3 t/ha potential			4.5 t/ha potential		
	yield t/ha	protein%	net $s	yield t/ha	protein%	net $s	yield t/ha	protein%	net $s
nil N	**1.96**	**9.5**	**$132**	2.54	8.7	$209	2.87	8.4	$253
30 N	1.99	10.7	$104	**2.86**	**9.2**	**$220**	3.41	8.7	$294
60 N	1.92	12.1	$60	2.99	10	$207	**3.76**	**9.1**	**$309**

for the APW pay grade. The yields, protein and returns are simulated according the nominated potential yields. There is no account taken of increased screenings from over fertilising which will further reduce returns.

Table 12.1 is based on an example of a sandy gravel paddock on sandplain with moderate fertility after a canola crop following several years of pasture. The dollar values are net of nitrogen fertiliser costs and other costs of $150/ha. The likely yields are poor – 2 t/ha in a decile 2 season, average – 3 t/ha in a decile 5 season and good – 4.5 t/ha in a decile 8 season (without too much water logging).

Similarly table 12.2 is based on a lower rainfall area example. This example is on poor pasture with reasonable organic carbon of 1.4 per cent. Reasonable yields are based on high stored soil moisture at sowing, margins are based on fertiliser costs as in table 12.1 but only $120/ha other costs.

Both tables show optimum returns from matching nitrogen to potential yield using the SYN program. There are lower returns for both over and under fertilising. For the selected parameters in these tables, more money is lost from over fertilising in a poor season than not enough nitrogen in a good season. This is because money is spent on fertiliser while reducing yield. The tables do not reflect the extra losses from higher screenings when too much nitrogen is applied. Experiments in seasons with a poor finish show that protein increments are not sufficient to offset the lower yield and higher screenings.

At the crop price and fertiliser cost used, optimum return is below maximum yield with protein of about 9.2 per cent. As grain returns per ton increase while nitrogen fertiliser costs remain the same, optimum returns are generated at higher yield and associated higher protein level but will not be any higher than 10-10.5 per cent protein. At higher nitrogen fertiliser prices and higher protein increments of $13 to $15 per ton for each percent of protein up to 10 percent, optimum return to nitrogen fertiliser is at maximum yield with grain protein around 10 per cent.

Table 12.2: Influence of potential yield and nitrogen fertiliser rates on expected yield, protein and margin of wheat in a 350mm rainfall area. 2005 on farm prices of APW $150/t

	2.3 t/ha potential			2.9 t/ha potential			4.0 t/ha potential		
	yield t/ha	protein%	net $s	yield t/ha	protein%	net $s	yield t/ha	protein%	net $s
nil N	**2.28**	**9.8**	**$216**	**2.72**	**9.1**	**$275**	3.26	8.6	$347
20 N	2.30	10.5	$198	2.85	9.6	$272	3.56	8.8	$366
50 N	2.24	11.6	$156	2.90	10.4	$247	**3.84**	**9.3**	**$373**

13. In-crop tactical nitrogen

Delayed application in both high and low rainfall areas allows a better forecast of crop yield potential before nitrogen is applied. Delayed application also reduces the risk of leaching and denitrification losses in high rainfall areas. There are many experiments showing that banded nitrogen fertiliser applied at sowing is often the most effective time and method of application, because adequate nitrogen is required for setting up the head and spikelet numbers for yield potential. We need to balance the risks of such a strategy with the confidence of better matching the nitrogen rate with the yield potential at later times of application. Split nitrogen application allows sufficient nitrogen to be applied at sowing or early tillering to set up yield potential and monitoring seasonal conditions to match additional nitrogen to expected yield and target protein. This approach has limitations if you are in very short growing season country (Geraldton) or you are in country where there is doubt that it will be trafficable after seeding.

In any rainfall area there is a range of seasonal outcomes leading to a range of potential crop yields. Even in low rainfall areas, potential yields vary between less than 0.5 t/ha and over 4 t/ha. Farmers need to have a nitrogen strategy to limit costs in poor seasons and take advantage of good seasons.

In order to match nitrogen to seasonal conditions, yield forecasting and nitrogen decision tools can be used to take account of the influence of season to date and projected rainfall likelihood. These tools can be as simple as monthly rainfall deciles and a proportion of the French and Schultz potential or as sophisticated as daily time step models like APSIM as delivered by Yield Prophet ®.

There are many tools and programs used by farmers and their advisers to calculate nitrogen supply in a paddock and the fertiliser requirement for a target crop yield and protein. None of them are useful unless there is an intelligent yield target or better still, a range of probable yield targets with appropriate nitrogen rates calculated for each. It is not appropriate to use average yields and paddock conditions as the cost of getting nitrogen rates wrong is considerable when up to $100/ha is spent on nitrogen fertiliser.

The question arises, how late can I apply nitrogen fertiliser and get an acceptable result? Experiments in the course of this project and elsewhere show that provided the crop has not suffered severe nitrogen stress, applications as late as booting boost both yield and protein in responsive situations.

The overall strategy is to apply nitrogen as the crop develops according to current yield expectations. Split applications are generally as good as the best single time of application, but the best time, like the best rate, is known after the season has passed. In 2004, with out leaching, applications split between tillering, stem elongation and booting were as effective as the same total amount applied at tillering.

Crops can be sown with sufficient nitrogen for a low yield expectation. Figure 13.1 shows a decision tree of nitrogen applications according to the progress of the season. If a poor season develops then there is sufficient nitrogen for the crop. During late tillering, if an average or better season is developing, more nitrogen can be added to supply an average crop. During stem elongation to ear emergence, a further assessment of the season is made. A continuing average season is already supplied with enough nitrogen fertiliser. A very good season will require more nitrogen but the rules of late application still need to be observed - good soil moisture and a reasonable prospect of follow-up rain. Unfortunately, if the season dries up there will be too much nitrogen. It is unlikely that a season that starts poorly will turn into an above average season after tillering. This logical approach leads to a better chance of matching nitrogen to crop yield potential.

The range of expected yields depends on the stored soil moisture at sowing, local climate characteristics, rain during the growing season and soil properties including Plant Available Water holding capacity and subsoil constraints. Rates of fertiliser will depend on the cost of that nitrogen fertiliser, price of grain and a grower's attitude to risk.

An example for the Scaddan area would cover the yield range of 2.5, 3.2 and 4.2 t/ha. The paddock has an expected nitrogen supply of 100 kgN/ha which together with the sowing fertiliser of 70 kg/ha DAP (13N) is enough to grow 2.5 t/ha at 10 per cent protein. If the season looks average (3.2 t/ha) or better at late tillering then an additional 25 kgN/ha is applied. Only if the yield potential looks greater than 3.5 t/ha then careful consideration should be given to a further late application of 25-30 kgN/ha at flag leaf emergence to maintain protein while benefiting from the prospect of the high yield.

In dry areas with less certain spring conditions a modification to this approach would be to sow crops with enough nitrogen for an average crop. This would reduce the problem of missing a rain event to wash top-dressed N fertiliser into the crop root zone. In higher

Figure 13.1: Crop development and nitrogen fertiliser decisions for growth stages.

rainfall areas, applications can be delayed to later in the application windows shown in figure 13.1 with less nitrogen applied at tillering and more deferred to stem elongation to avoid losses in leaching and waterlogging situations.

The general principle is to track seasonal conditions and adjust nitrogen inputs accordingly using nitrogen decision tools to select appropriate rates for the updated yield targets. There are still problems with rain stopping after the last applications in early September as happened in 2004 and 2006 and very wet paddocks that remain boggy for long periods in the season. Research in a high rainfall cropping project based west of Katanning is showing the benefit of delaying nitrogen applications until the water logging has passed. (N Simpson pers com.)

14. Nitrogen decision systems

There are many steps that farmers use to make decisions on nitrogen fertilisers. The simplest is to do what has previously been done with some adjustment for recent experience and cash flow. Fertiliser decisions are made throughout the year as indicated in table 14.1. Sophisticated decision making techniques can be used at many decision times by growers and their advisers.

While N is a major nutrient we also need to take account of other major nutrients and trace elements to ensure nothing is limiting - otherwise N fertiliser will be less effective. Physical and chemical soil conditions need to be assessed to ensure good root development and recovery of nitrogen. Root disease, rotation, weeds, variety, in fact the whole agronomy of the crop needs to be considered to ensure effective N uptake and profitable responses.

A range of decision tools is available to help with nitrogen decisions for yield and protein. With years of development and testing there is still a degree of uncertainty in their output because of the complexity of interacting factors influencing a biological result. None of the tools and recommendation systems developed has an extremely high degree of certainty - local experience and testing can refine the usefulness of any system. No system seems to outperform another over a run of seasons and paddock conditions but growers develop their own preferred techniques.

The Nitrogen Calculator

The Nitrogen Calculator is a card wheel calculator which estimates the amount of nitrogen available to a crop from both soil and legume residue organic sources based on soil organic carbon and paddock history. The crop nitrogen demand is calculated from expected yield, target protein level and efficiency of nitrogen uptake. The difference between supply and crop demand is the fertiliser requirement. There is no calculation of economic return and no effect of timing included in this system.

There are also stand alone electronic versions performing the same tasks for cereals and canola and the Rite Nitrogen Slide Rule for Barley which is a version specifically for Gairdner[Φ] and now Baudin[Φ] barley which also has a high requirement for nitrogen.

Select Your Nitrogen - SYN

SYN is a more complex spreadsheet model using MS Excel. SYN takes account of soil type, paddock history, organic carbon, seasonal rainfall pattern, source of N fertiliser, time of application, potential yield of crop, and cost of fertilisers to generate expected response curves for yield, protein and returns net of fertiliser cost.

SYN can generate response curves for a range of yield potential with a given nitrogen strategy. This allows decisions to be based on a range of potential seasonal outcomes.

Table 14.1: Sequence of nitrogen fertiliser decisions

Timing	Decision based on	Actions
October fertiliser orders	Average yields and N use Legume bulk in pastures and pulses Likely taxable income.	Standard order based on rates per hectare and previous history.
Sowing	Summer rainfall, grain price forecast, tax payable, N Calculators, SYN and PYCAL	Apply enough N at sowing for a low potential yield.
	Good stored soil moisture	Increase sowing N in lower rainfall areas.
Tillering	PYCAL yield probabilities, SYN or Yield Prophet®. Good establishment with no disease or weeds to reduce potential.	Review N applications to date in relation to potential yield.
	Early sowing, continuing surface soil moisture from good rainfall.	Increase tillering application rate.
Stem elongation	Rainfall to date compared to average, tiller counts, plant analysis or crop sensing to check N status. SYN runs.	Apply N according to decision tool outputs.
	Low tiller count for seasonal prospects and N applied	Add more N for tiller survival.
Booting	Rainfall to date. Yield Prophet® reports Recalculation of PYCAL. Compare yield and protein targets to applied fertiliser to date and soil N	Last reasonable chance for more N to maintain protein.
Post harvest	Compare yields and protein with calculated expectations.	Make records for next order.

Surface soil testing

Soil testing to 10 cm during the summer period is used to measure mineral nitrogen levels and organic carbon. Organic nitrogen sources mineralise over the summer period according to soil temperature and moisture. With significant summer rainfall when the soil is warm, large amounts of nitrogen are mineralised which is reflected in higher nitrate and ammonium levels than would be present in dry conditions.

Soil organic carbon provides an estimate of organic matter and associated organic nitrogen. There is a reasonably constant ratio of carbon to nitrogen in soil organic matter so organic carbon percentage is a good indicator of organic nitrogen. Organic carbon declines rapidly with depth on most soils in WA, there is little reason to sample for OC deeper than 10 cm and relationships have been developed for the surface 10 cm sample.

Other tests can be performed on surface samples such as Total Organic Nitrogen but the mineralisation rates still need to be estimated according to seasonal conditions.

Deep nitrate testing

Deep nitrate testing has been developed in eastern Australia on loams and duplex soils with clay subsoils. The soil is usually cored to 60 cm depth as close to sowing as practical with analysis either on the whole profile as one sample or the cores segmented to examine the distribution of mineral nitrogen through the profile. Total mineral nitrogen is calculated for the depth sampled and used as an indication of fertility. The proportion of nitrogen expected to mineralise from the organic matter in the surface 10 cm is sometimes added to the mineral nitrogen from the deep nitrate test and together with expected crop demand, is used to generate a requirement for fertiliser nitrogen.

There is variation in deep nitrate levels across a paddock. Root depth needs to be taken into account as crops will not get nitrogen below the root zone. Sampling needs to be done close to sowing. In deeper sandy and gravelly soils, little mineral nitrogen is stored in the profile and nitrate is subject to leaching before roots can develop.

Tissue testing, chemical and NIR analysis

Tissue analysis of plants during the growing season can be used as an indication of nitrogen status. The analysis can be performed using chemical techniques or Near Infra Red (NIR) spectroscopy. Despite representative sampling and accurate analysis, the crop still has to mature during uncertain spring conditions which will influence the final yield and protein. Such systems have been used in areas with reliable spring seasons. The main problem with any nitrogen tissue testing method is that the yield responses to late nitrogen vary markedly with many other factors, most of which depend on seasonal conditions beyond the control of the grower. (Bowden GRDC final report UWA 189)

Yield Prophet®

Yield Prophet is described in section 11 – Estimating potential yield. It can also be used as a nitrogen decision tool as rates of nitrogen fertiliser and timing of application are used to simulate likely responses according to the site being modelled. A series of runs are needed to generate an idea of response to nitrogen rates.

GreenSeeker™

The GreenSeeker is a hand held spectral scanner that measures a Normalised Difference Vegetation Index (NDVI). This is closely related to above ground biomass. NDVI values are measured in nitrogen rich strips across paddocks compared to the general paddock. The difference between these values together with the length of time between sowing and sensing and relationships developed for the region indicate the amount of nitrogen fertiliser required. At this stage there is very little calibration for WA or regional conditions.

Chlorophyll meters

These are electronic devices that measure the greenness of a crop by light transmission or reflectance. The Minolta SPAD 502 has been available for several years and is a handheld light transmission/absorbance measuring device that generates readings closely correlated with chlorophyll content and hence nitrogen content of the leaves. There are similar devices made by other manufacturers and also a green reflectance measuring device that measures canopy greenness from a short distance.

Similar to other electronic scanning devices the readings generated need to be calibrated locally with likely crop response and economics of nitrogen response in the light of uncertain spring conditions.

Anything that changes greenness will influence the accuracy of the system. Operators need to take care with disease, other nutrient deficiencies and toxicities, waterlogging, crop variety, herbicides, leaf age and shading, and position of measurement on a leaf. Most nitrogen recommendation systems developed for chlorophyll meters aim to fertilise crop to a high percentage of maximum greenness as determined by an over-fertilised nitrogen rich strip set up in the crop as a reference. The most reliable time for measuring a crop with these devices is early stem elongation (Zadoks 31)

Late nitrogen application check list.

A decision chart has been developed by Bill Bowden to assist decisions on nitrogen application during stem elongation and booting. Factors to consider are yield potential of the crop, growth stage, soil moisture, chance of following rainfall, current nitrogen nutrition and target grade.

The chart is included in appendix 1

15. Further reading and useful material

Baldock J, Sadras V & Mowat D (2003) 'Nitrogen management for yield and quality.' In SA Crop Updates 2003

Bowden JW et al (2003) 'Select your Nitrogen. A decision tool for quantifying nitrogen availability and crop response in broad-acre farming systems.' (Department of Agriculture Bulletin 4600)

Bowden JW (2000) 'Nitrogen management for increased grain protein in the WA wheatbelt' (GRDC final report project number UWA189)

Bowden JW & Diggle A(1996) 'Nitrogen Calculator.' (TOPCROP West kit)

Parish J, (1963) 'Sampling premium wheat crops.' Journal of Agriculture WA Vol 4 p687

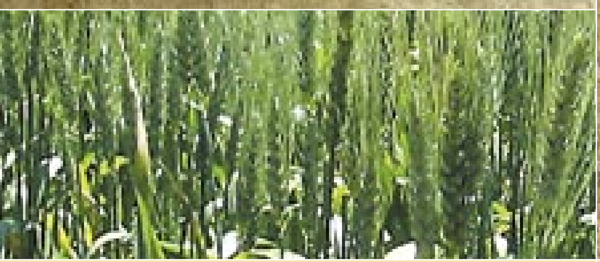
Tennant D & Tennant S (2000) 'Potential Yield Calculator vers 2.31' (Department of Agriculture WA)

APPENDIX 1: Checklist for late nitrogen applications on wheat

Should I apply extra nitrogen to my wheat crop now? Before you make this decision, check the following

Critical factors	Why?	How?	Further help**
NITROGEN STATUS Is the crop deficient? How much nitrogen in the soil is available for my crop?	If your crop is not currently n deficient, and soil supplies are adequate to meet the demands of the current yield potential, then you will not get a paying response to nitrogen now.	**Plant indicators** • Colour/symptoms • Tillers/plant, tillers/m2 **Soil indicators** • N supply from rotation • Soil type and OC% • Rainfall distribution and leaching	**Tissue testing** • Standard analysis services • Crop sensing **Calculation** • SYN
GROWTH STAGE What is my plant stage NOW? Is it too advanced to respond?	Nitrogen is required early in plant development to initiate heads and grains. It is needed later to maintain green leaf area, tillers and grain numbers. However, post anthesis application will usually be too late to give a paying response.	**Weeks from seeding** • Late tillering • Stem elongation • Boot to ear emergence • Anthesis (Flowering) • Post Anthesis – Too late !	**Decision tools** • FLOWERCAL • Zadok's - growth scale – in the Wheat Book • Yield Prophet
YIELD POTENTIAL How much would my crop produce? Is there anything that will constrain the current potential?	If the crop does not have the potential to go 2 to 3 t/ha, then increases in yield will be unlikely to pay for the fertiliser. Increases in protein percentage will usually only pay for the nitrogen if they put your crop into a noodle segregation.	**Heads per metre squared** • Count heads/metre of row and allow row spacing. Assume 100 heads/metre squared equals 1 t/ha. • Adjust down to 75% of this • Dig up, wash and inspect root health and depth. Physical and chemical hardpans? **Weeds, diseases and insects** • Inspect for competition and damage.	**Decision tools** • PYCAL - Potential Yield Calculator • Yield Prophet • Use the TopCrop checking system. • Consult an agronomist
STORED SOIL MOISTURE What is the soil like? What is its capacity to store water? Is it now fully charged with water?	The stored moisture in the soil determines the chances of a crop finishing and so realising its potential yield. Rainfall patterns and soil type can give good Indications.	**Calculate it roughly** e.g. how many days before rain needed if water lost at 5 mm per day? Sandy soils. hold less than 80 mm in the root depth and are deeply drained. Sandy loam soils hold about 150 mm in the root depth. Clay and shallow duplex soils may waterlog and have evaporative losses. Mallee clay subsoils hold about 80mm in the root zone.	**Decision tools** • PYCAL - Potential Yield Calculator (before end July for soil moisture tool) • Yield Prophet • Auger holes
FINISHING RAINS Is it likely that we will get good finishing rains?	Rain in the immediate future washes fertiliser nitrogen into the root zone and allow plants to take it up. Finishing rains help the crop meet its potential.	• Enough to wash in the nitrogen fertiliser and keep the surface wet? • Is a top up to the stored moisture needed?	**Rainfall records and projections** (what are the chances of given rainfall events?) • PYCAL rainfall deciles • DAFWA growing season outlook • www.bom.gov.au - season outlook • Climate Calculator • Rainman
Economics Will yields increase sufficiently or higher protein change the likely delivery grade?	Economic response unlikely if only protein is increased with out changing to a higher delivery grade.	• Calculate extra value of expected yield, protein and grade response.	**Decision tools** • SYN • Yield Prophet • Golden Rewards matrices

**For further help and technical information consult your closest Department of Agriculture and Food Office and/or agribusiness consultants. Developed by JW Bowden.



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