Nutrition concurrent session

Changing nutrient management strategies in response to declining background fertility: The economics of deep Phosphorus use.

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Phosphorus, deep placement, starter P, multiple nutrient limitations, residual value

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Take home message:
Soils supporting northern grain production are changing in response to cropping, with native fertility declining. Immobile nutrients like phosphorus (P) need to be placed to meet both seedling and older crop demands, with root system distributions and soil moisture playing a key role in crop demand, yield response and fertiliser recovery. Residual value of applied P for subsequent crops is generally good, and responses are recorded over multiple crop seasons. This holds the key to profitability of deep P applications, which can be made infrequently to cater for varying seasonal conditions and stubble loads. Getting P nutrition right can improve productivity and profitability by improving system WUE and returns on other crop inputs (like N), but only if other nutrients are also adequate. This paper explores the responses to P in cropping systems, primarily focussing on deep placement to address infertile subsoils. It looks at the costs and returns using simulated crop yields (to explore seasonal variability) in combination with trial data from sites in northern NSW and Qld grain growing areas. The key findings suggest deep P applications are most profitable when the combination of climate and soil characteristics allows higher potential yields.

Phosphorus (P) is an increasingly important fertiliser nutrient needed to support productivity and profitability of northern region cropping systems. It is a nutrient that is needed in small amounts (but at high plant tissue concentrations) to support the establishment of grain numbers at floral initiation in grain crops, very early in crop development. This is why the practice of using starter P fertilisers (placed with or very close to the seeding trench and hence the developing seedling root system) evolved. But P is also needed in increasingly larger quantities in later stages of growth to establish a high tiller density (in cereals), to help develop a vigorous root system and to grow biomass and ultimately fill grains (in all species). That later season P has traditionally come from native subsoil P reserves, but as we remove more and more in harvested grain the need to introduce fertiliser P sources to replenish that is becoming more urgent. As one can imagine, the placement of starter P fertiliser to meet the demands of a young seedling with a very small root system will be quite different to that needed to meet demands of a well established plant living on subsoil moisture during flowering and grain filling.

Some soils were low in available P reserves from the start and have required P inputs from early in their cropping history. However for many others the need to apply P is relatively new or still non-existent, due to either high native P fertility or relatively short crop histories. As a result, we in the north are still working out where and how best to use P in our fertiliser programs. This is a major contrast to southern and western systems where soil P was in its native state almost uniformly low, and long term P fertiliser use now has growers questioning when to stop (or at least reduce rates). In many ways the northern grains region (NGR) is at the opposite end of the P fertility continuum to the rest of Australia, in that we are starting to ramp up P fertiliser use.
Another reason we are different is how we farm. With the possible exception of parts of the central west of NSW on lighter soils, soil moisture storage during fallows and subsequent extraction and use during a crop season are as important, or in many cases more important, than in-season rainfall for achieving a profitable yield result in most of the NGR. Last winter (2013) was an extreme example, where many crops in Qld and NE and NW NSW were successfully grown on little or no effective in-crop rainfall. While not always to this extent, subsoils and root activity in them are the keys to our success in most northern cropping seasons. However it is not just water we extract from those subsoils, with availability of nutrients in those same layers essential to sustain growth of plants. Nutrients removed from those subsoil layers have to be replenished if we wish to keep successfully farming subsoil moisture, and while some nutrients like nitrogen (N) and sulfur (S) can be moved back into those layers as soil water stocks replenish, this transfer method doesn’t work for immobile nutrients like P and potassium (K). Replacing subsoil P and K requires either placing fertiliser into those layers directly, or moving fertilised topsoils deeper into the profile with some sort of inversion tillage. The latter is generally not a popular or feasible option in our largely zero tillage, heavy clay soils, given our reliance on stubble cover for water infiltration and the often unfavourable chemical characteristics of subsoils that would be brought to the soil surface.

This then generates a series of questions around (i) whether we would expect to get a crop response to applied P; (ii) how and when that P should be distributed across the soil profile; and (iii) perhaps most importantly, does it pay and when? We explore all three issues, using experimental data and case studies, in combination with APSIM modelling using regional climate data. We have used this climate data to explore historical variation in crop productivity in different regions, in addition to using seasonal rainfall distributions to classify season types and their frequency. The latter has proven to influence the magnitude of response to P application in experimental results, and so will be an important influence on the expected profitability and payback periods as well as the risk of the deep P placement.

**Where would we expect P responses?**

Soil testing of both topsoil (0-10cm) and subsoil (10-30cm) layers is the key to determining whether a response to applied P (starter or deep P or both) could be expected. While we are currently working to refine these fairly broad soil categories, and to explore crop requirements, our best estimates for the Vertosols appear in Table 1 below.
Table 1. Critical P values used to determine likely response or drivers of P availability in northern Vertosols

<table>
<thead>
<tr>
<th></th>
<th>Surface (0-10cm)</th>
<th>Subsoil (10-30cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colwell P</td>
<td>&lt;20-25 mg/kg Likely to get a response to</td>
<td>&lt;10 mg/kg Likely to get a response to deep P placements, unless BSES P high</td>
</tr>
<tr>
<td></td>
<td>starter P. Critical values may be lower in some areas.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25-40 mg/kg Unlikely to respond to starter P</td>
<td>10-20 mg/kg Probably no response to deep P provided root volume is accessible to roots</td>
</tr>
<tr>
<td></td>
<td>&gt;60 mg/kg Ensure good groundcover to limit erosion risk!</td>
<td>&gt;100 mg/kg Unlikely to see P deficiency in your lifetime</td>
</tr>
<tr>
<td>BSES P</td>
<td>&lt;25 mg/kg Limited evidence of residual fertiliser accumulation</td>
<td>&lt;30 mg/kg Limited reserves of slowly available P. Consider replacement of removed P once every 5 years.</td>
</tr>
<tr>
<td></td>
<td>25-100 mg/kg Probably naturally high in native P minerals or accumulating fertiliser residues; limited use for replacing starter P but likely to contribute to later crop uptake if topsoil is moist</td>
<td>30-100 mg/kg A large grey area. Availability to plants will depend on solubility of native minerals. Try test strips if Colwell P &lt;10 mg/kg.</td>
</tr>
<tr>
<td></td>
<td>&gt;100 mg/kg High residual fertiliser load; slowly available to surface roots</td>
<td>&gt;100 mg/kg Potential to slowly replace Colwell P reserves and support crop growth in large soil volumes</td>
</tr>
</tbody>
</table>

Of course, a soil test that is lower than a critical concentration or range does not guarantee a response to applied fertiliser. Rather, these critical values or ranges are indicators of a probable response with favourable seasonal conditions and agronomic variables. You will also note there are some pretty broad differences between responsive and definitely non-responsive soils, with this large grey area where we are currently researching to better refine soil test-crop response guidelines.

What response would we expect in yield in different seasons??

This is clearly a work in progress, but we are starting to be able to make some general observations from trial data and existing work done in the NGR. We will restrict this study to soils where we are confident we will get a response to applied P. That is, for Colwell P <25 mg/kg in the 0-10cm layer in the case of a starter P application, and when Colwell P is <10 mg/kg and BSES P is < 30 mg/kg in the 10-30cm layer in the case of deep P. Key points are as follows –

- The frequency of grain yield responses to starter P would be in the order of wheat > long fallow sorghum, mungbean and chickpea > short fallow sorghum. The magnitude of the responses varied, but typically ranged from 0-10%, except in a mungbean crop where soil P was very low and responses were much larger in relative terms.
- All crops (wheat, chickpea, sorghum and mungbean) have shown responses to deep P application.
• Responses to deep P, assuming other nutrients like K and S were sufficient, have averaged ~20% in crop yields in the 1st and 2nd season (few sites have been monitored any longer). Some responses have been larger (50–70%) under particular agronomic (e.g. heavy nematode pressure) or climatic (limited or no effective in crop rainfall) circumstances.

• The strongest responses to deep P in grains (wheat and sorghum) occurred when post-planting rainfall allowed the establishment of secondary roots and tillers, which are the main pathways to plant P acquisition and increased yields. In wet years when the topsoil was readily accessible, or in extremely dry years, responses were more limited. By contrast, the strongest responses in chickpeas were in years with little effective rainfall, especially up to pod loading, although consistent responses were still recorded in wetter seasons.

Except for wheat, there is very limited data on responses to starter P by crops in the NGR and there is no historic data on responses to deep P for any crops – other than what we have generated in the last few years. As a result, the representation for different crop species, soil types and seasons is somewhat limited. However we would suggest there are three basic types of seasons, with characteristics that influence crop response to deep P. We have loosely termed these as

*Type 1 seasons, or ‘dry’ starts* - those years with little or no effective rainfall from planting until after tillering;

*Type 2 seasons, or the ‘wet start/dry finish’ years* - those with enough rain to ensure good early growth, secondary root development and tillering but serious later stress ensuring a strong reliance on subsoil moisture; and

*Type 3 seasons or ‘wet’ years* – no severe crop stress, with an expectation that more regular rainfall will ensure the top soils have plenty of active roots (although we may be battling foliage diseases in the hope of securing high yields).

The frequency of these types of seasons obviously varies (winter v summer, and region to region), and we have used the climatic record from key sites across the NGR to estimate the frequency of occurrence. We have also used APSIM to generate yield distributions for these seasons on high (240mm) and low (120mm) soil plant available water storage capacity (PAWC) and different starting profile moisture contents (full, 2/3 full or 1/3 full). These simulations were used to estimate average yields of our four key crops (wheat, chickpea, mungbean and sorghum) in each season type, with these averages used to estimate the potential yields from which losses due to P deficiency can be calculated. These data are shown for wheat and chickpea, sown on a 2/3 full moisture profile in soils with either a 120mm or 240mm PAWC, in Table 2.
Table 2. The frequency of occurrence of different season types and the simulated crop yields for wheat and chickpeas under those seasonal conditions for different production centres and soil types. These data are derived from profiles assumed to be 2/3 full at sowing, with similar data available for sorghum and mungbeans from spring and summer sowing windows. These yields would be achieved if there were no nutrient limitations.

<table>
<thead>
<tr>
<th>Location</th>
<th>PAWC</th>
<th>Dry start</th>
<th>Wet start, dry finish</th>
<th>No serious water stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>120</td>
<td>240</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Yield</td>
<td>% Yield</td>
<td>% Yield</td>
</tr>
<tr>
<td>Emerald</td>
<td>Wheat</td>
<td>40%</td>
<td>850</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>28%</td>
<td>540</td>
<td>28%</td>
</tr>
<tr>
<td>Dalby</td>
<td>Wheat</td>
<td>12%</td>
<td>980</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>7%</td>
<td>660</td>
<td>7%</td>
</tr>
<tr>
<td>Goondiwindi</td>
<td>Wheat</td>
<td>10%</td>
<td>1070</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>5%</td>
<td>720</td>
<td>5%</td>
</tr>
<tr>
<td>Gunnedah</td>
<td>Wheat</td>
<td>6%</td>
<td>880</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>5%</td>
<td>990</td>
<td>5%</td>
</tr>
<tr>
<td>Walgett</td>
<td>Wheat</td>
<td>11%</td>
<td>775</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>9%</td>
<td>630</td>
<td>9%</td>
</tr>
<tr>
<td>Condobolin</td>
<td>Wheat</td>
<td>6%</td>
<td>780</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
<td>4%</td>
<td>590</td>
<td>4%</td>
</tr>
</tbody>
</table>

A few key points to make about this analysis are (i) the frequency of Type 1 seasons (dry starts) is relatively low (5-10% of years) except in the central Highlands of Qld, where it ranges from 30-40% of years; (ii) there is a strong interaction between Type 2 late stress seasons and soil type/PAWC, with the higher PAWC reducing the frequency of late stress seasons by an average of 30% (wheat) to 40% (chickpeas). Average yields in those less frequent Type 2 seasons were still 800 (chickpeas) - 1200 (wheat) kg/ha higher in the high PAWC soils; (iii) Similar effects were evident in the summer crops (not shown), although the frequency of Type 1 seasons was much higher (average of 40% for sorghum and 21% for mungbean) than in winter crops. Higher PAWC reduced the average frequency of late stress summer seasons by an average of 16% (sorghum) to 30% (mungbeans), with average yields in those late stress seasons 1550 (sorghum) and 500 (mungbeans) kg/ha higher in the high PAWC soil.

The yield losses due to low P incurred in the different seasonal types are clearly pivotal in any such analysis of the costs and benefits of ensuring adequate P nutrition. The estimates used in this analysis are preliminary and based on (in some cases very) limited data. However we think the discounts or yield reductions shown in Table 3 below are realistic for soils where we are very confident P responses will be obtained. We have presented these as total yield response to applied P (the sum of starter and deep P), although we would note that responses to starter P range from 0% to 10% of yield potential, with most consistent responses in higher yielding seasons. Under the right seasonal conditions, overall P response can be much greater. These estimates of P responses have been used to work out the opportunity cost of lost yield if P applications are not made and placed in the right part of the soil profile. These values are used to estimate the costs and benefits of
P fertiliser application. We have used average prices for each crop: $200/t for sorghum, $250/t for wheat, $400/t for chickpeas and $700/t for mungbeans. Clearly, differences in yield potential due to PAWC will have a major impact on the absolute yield response to applied P

**Table 3.** Estimates of relative yield losses that would be experienced if fertiliser P was not applied for different soils and season types. These effects are due to a combination of starter P and deep P, and would reduce the simulated potential yields such as shown in Table 2.

<table>
<thead>
<tr>
<th>Season</th>
<th>PAWC</th>
<th>Wheat</th>
<th>Sorghum</th>
<th>Chickpeas</th>
<th>Mungbeans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry start</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Wet start, dry finish</td>
<td>10%</td>
<td>10%</td>
<td>15%</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>No serious water stress</td>
<td>15%</td>
<td>15%</td>
<td>10%</td>
<td>20%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Season</th>
<th>PAWC</th>
<th>Wheat</th>
<th>Sorghum</th>
<th>Chickpeas</th>
<th>Mungbeans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry start</td>
<td>10%</td>
<td>10%</td>
<td>30%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Wet start, dry finish</td>
<td>25%</td>
<td>25%</td>
<td>25%</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>No serious water stress</td>
<td>15%</td>
<td>15%</td>
<td>10%</td>
<td>15%</td>
<td></td>
</tr>
</tbody>
</table>

**How much do we need to apply and what is the residual value of applied P?**

This is currently part of the focus of the existing trial program in UQ00063, with responses to different P rates assessed in both the initial crop year and subsequent seasons through a crop rotation. We know from work at IPL long term fertiliser trial sites like Colonsay and Tulloona that roughly half of the net P removal in our cropping soils has come from the subsoil (Wang *et al.*, 2007), so we assume that future fertiliser programs will ultimately be a mix of starter and periodic deep P applications if they are to be sustainable.

In our analyses here we have assumed deep P application rates of either 20 or 40 kg P/ha (eg. 100 or 200 kg MAP/ha), with responses available undiminished over a 3 (20P) or 5 (40P) year cropping period. While most of this will be a ‘new’ fertiliser input in some areas, in others at least part of this P may be able to be diverted from what is currently being applied in starter fertilisers. Our experience suggests that, provided metering systems are adequate to ensure an even fertiliser distribution along the seeding trench (easier with liquid P forms), effective rates of starter P can be as low as 3-4 kg P/ha in row spacings of 100cm or greater (eg. summer sorghum) and 5-6 kg P/ha row spacings of 25-50cm (wheat and chickpeas). The response from higher rates of starter P is likely to be marginal, and although available to roots in subsequent seasons (provided topsoils are wet), could probably be used more efficiently as part of deep applications.

Our experience in soils with low Phosphorus Buffer Indices (PBI) across the region (ie. most of the major cropping soils) is that residual value of these large P applications into subsoils is excellent and covers multiple crop years. Papers in the 2012 GRDC Updates have shown applications of 40 kg P/ha providing consistent yield responses of 15-20% over 6 consecutive crop seasons at Brookstead. Additional P uptake in crop biomass was as high as 10 kg P/ha in some seasons, but the rate of removal of fertiliser P in grain was often only 20-25% of that found in biomass, so the continued yield responses were consistent with a mass balance that suggested residual P should be available. The proportion of the applied P still in the subsoil is debatable, given the quantities returned to the soil surface as residue.
What does it cost to deep place P?

We are indebted to growers in central and southern Qld for providing estimates upon which to base these figures. These operators have used purpose-bought strip tillage equipment or modified planters capable of deep sowing chickpeas to place fertiliser at ca. 20cm depth. Both sets of equipment were 12m wide and placed fertiliser at 50cm or 75cm band spacings (we would recommend bands 50cm apart or closer if possible to get the best response), and operated at 7-8 km/h, using about 60-65L/h in diesel. We have estimated total application costs at between $30 and $40/ha, which are added to costs of MAP or a mix of MAP and KCl (if both P and K are limiting) that vary from $750-$850/t bulk. Thus the cost of deep placement of 100 kg/ha product is estimated at $105-115/ha after every 3rd crop, or $180-$210/ha for 200 kg/ha after every 5th crop, with this longer duration based on results from our trials at Brookstead (see next section). Allowing for the interest on borrowing to afford those outlays over the residual period would raise the total cost of deep placement by 25% (3 year) or 40% (5 year), assuming borrowing at 8% interest. We have assumed these costs are additional to what is being incurred now (including any use of starter P).

We think this is reasonable given possibly reduced costs associated with lower starter P rates but an increased N fertiliser cost associated with higher yield potentials in the cereal crops.

So does it pay to deep place P?

Simulations – We have used the simulated potential yields (as illustrated for winter crops in Table 2) and the discounts that would be incurred from low P (Table 3) to estimate the average responses to applied P for each crop in each season type. Then for each location and PAWC soil we have calculated an average yield response across the climate record which is weighted for the different frequencies of each season type. For example, on a 240mm PAWC soil in Gunnedah growing wheat, there were 6% Type 1 seasons with an average yield of 2.5 t/ha, 30% Type 2 seasons with an average yield of 3.3 t/ha and 65% of Type 3 seasons with an average yield of 5.4 t/ha. Using these figures and the relative yield losses that would be incurred without adequate P in each season type shown in Table 3, we estimate the average annual loss in wheat yield resulting from inadequate P availability on a responsive soil would be 840 kg/ha.

We have made similar calculations for each crop, soil type and location, and assembled some 5 crop rotation sequences (Fig. 1) which show the estimated cumulative lost production ($/ha) that we predict would be overcome by a 200 kg/ha deep MAP application at a cost of $180-$210/ha plus any allowances for borrowing costs. Data clearly show greater returns from applying P on a higher PAWC soils (reflecting the greater productivity of such soils in most seasons), and to some extent higher returns on summer only or mixed summer-winter crop rotations. The latter would appear to be due to the relatively high returns generated by mungbeans valued at $700/t, and given the quality/price uncertainties with this crop, those findings should be treated with caution.

Perhaps the key finding is that positive returns were generated from deep placement of P in responsive soils in most situations – the exceptions being on low PAWC soils with summer-dominant rotations in Walgett and Condobolin (not commonly grown anyway), and exclusively winter crop rotations at Emerald. On low PAWC soils these returns barely exceeded costs of application and would represent a relatively poor return on investment, but in high PAWC soils returns typically ranged from $2-$5 for each dollar invested in deep P application.
Figure 1. Estimated returns from investment in deep P on responsive soils with 120mm or 240mm PAWC in centres across the northern grains region. Returns are based on median yield responses to applied P across 5 year crop sequences involving wheat (Wh), sorghum (Sg), chickpea (Cp) or mungbeans (Mb).

How does this line up with experimental results - These simulated results can be contrasted with actual case studies from various sites conducted at locations across the region and followed for at least 2 consecutive crops.

• At Brookstead, our longest running site, we produced an additional 2100 kg/ha sorghum and 1200 kg/ha wheat over 6 crops from 2006/7 to 2011, which would have returned an extra $720/ha.

• At Capella we produced an extra 900 kg/ha chickpeas in 2012 and an extra 200 kg/ha wheat in 2013, which would be worth $410/ha for the first 2 crops after application using average crop values.

• At Gindie we produced an extra 600 kg/ha sorghum in 2011/12 and an extra 500 kg/ha chickpeas in 2013, which would return an extra $320/ha for the first 2 crops after application using average crop values.

• At Jandowae we produced an extra 0.5 t/ha wheat in a dry 2009 winter, followed by an extra 1.5 t/ha sorghum in 2010/11 which would return an extra $425/ha for the first 2 crops after application. Unfortunately a following chickpea crop was lost in the wet 2011 winter.

• At Wondalli we produced an extra 500 kg/ha sorghum in 2008/09 followed by an extra 650 kg/ha wheat in 2011, which would return an extra $263/ha for the first 2 crops after application using average crop values.

• At Binigu we produced an extra 1.2 t/ha of wheat in 2011 followed by an extra 1 t/ha sorghum grain in 2011/12, returning an extra $500/ha.
Assuming similar application costs at each of these sites, all results support the conclusion that deep placed P would likely provide returns to growers well in excess of the application costs. The fact that most sites achieved those returns within 2 crop seasons after deep P application may at least partly reflect the string of wetter seasonal conditions in recent years, although the results from Jandowae, Capella and Gindie all included dry seasons in at least one of the crops followed.

The experimental program is continuing, and further data will be collected to give greater surety of financial returns from adoption of deep P placement, and a better understanding of the impact and longevity of different deep P rates. For those considering deep P applications in their cropping program, a few key factors need to be considered –

- Make sure you test the paddocks first, to ensure a P response is likely.
- Make sure P isn’t the only limiting nutrient – secondary limitations to yield from K or S can limit an expected P response.
- If you are raising grain crop yield potentials above what is normally experienced, make sure there is adequate N available to achieve that higher yield goal.
- If you are diverting some of the P fertiliser used in starter applications to periodic deep P applications, make sure the rate you apply is still adequate to meet seedling P demand, with the key factor likely to be uniformity of fertiliser distribution along the seeding row.

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Economics and management of phosphorus & multiple nutrient decline: placement, costs and returns over time, and factors influencing response and risk

_Bede O’Mara, Incitec Pivot Fertilisers, Toowoomba_

**Key words**
Phosphorus, Colonsay, Tulloona, long term experiments, crop nutrition, agronomy, soil testing,, fertilisers, economics, deep P

**GRDC code**
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**Take home messages**
- Understand Colwell P at 0-10cm over time to ensure crop has nutrient access early where many physiological processes begin, before addressing P or other nutrients at depth.
- Soil sampling strategies for both surface and subsoil should be consistent and repeatable to allow critical analysis of results over time (N, P, K & S).
- Understand your rotation, your soil, surface Colwell P status, machinery capability and cashflow position before venturing a significant investment in deep fertiliser strategies, but ensure it is based on scientific evidence.
- Better placement of phosphorus has the potential to increase phosphorus use efficiency in cropping systems on all soil types.
- Test strip, test strip, test strip.
- Nitrogen, nitrogen, nitrogen.

**Background**
Farmer and agronomist frustration with variable responses from at-sowing applied phosphorus (P) fertiliser has seen considerable debate as to why. Thus far this research suggests that P and multiple nutrient stratification in minimum or zero-till farming systems is of genuine concern in the Northern Grains Region.

The rundown of low mobility nutrients (P & K) in the subsoil increases the importance of placing these nutrients in the zone where moisture and therefore active root growth is most likely. The compromise of course is the energy cost in placing nutrients at depth and the associated moisture loss – these factors suggest that a single application for a number of crops may be the solution. Quantification of these factors and associated economics are ongoing.
How much P is enough (0-10cm)?

The Better Fertiliser Decisions Cropping database (2013) indicates that, from 207 P rate trials in wheat on Black Vertosols across the CQ, SQ & N NSW grain growing regions, that the critical Colwell P value for 95% of max yield is 33 mg/kg with a range of 29 – 37 mg/kg (figure 2). At 90% relative yield, 24 mg/kg of Colwell P concentration is required with a range of 21 – 27 mg/kg.

If the soil series is expanded to include all vertosols, (some 328 trials) for the same regions, the critical Colwell P value at 95% relative yield is 30 mg/kg, with a range of 27 – 34 mg/kg. At 90% relative yield, 22 mg/kg of Colwell P concentration is required with a range of 20 – 25 mg/kg.
Figure 3. Better Fertiliser Decisions Cropping database: all Vertosol soil data for CQ, SQ & N NSW.

We can then apply our own actual Colwell P status of soils sampled over larger, smaller or similar regions to that of the BFDC database.

We can use these established critical levels to understand P status across cropping regions using bulk laboratory data. For example, figure 4 shows that around one a quarter of Queensland cropping soil samples taken in 2011/12 were likely to be P responsive while another quarter were possibly responsive based on BFDC critical levels for all vertosols.

Figure 4. 0-10cm soil test (mg/kg Colwell P) – Qld 2011/12
Data from the northern cropping zone (Nth NSW – CQ) suggested a slightly different trend (figure 5).
An examination of Colwell P values for the Central and Southern Queensland, and Northern NSW grain growing regions indicates 57% of samples taken pre-winter crop 2013 were at or above a critical value of 22-24mg/kg Colwell P (Figure 5).

![Figure 5](image)

**Figure 5.** 2013 0-10cm Colwell P, Northern NSW, Central Qld and Southern Qld

Know your soil-how is your Colwell P at 0-10cm?

Soil test values under different experimental regimes at the Colonsay (Table 1) and Tulloona (Table 2) experimental sites show clearly that an accumulation of Colwell and BSES P in the surface layer (0-10cm) has occurred where phosphorus was applied at three rates at sowing for each crop sown at each site.

**Table 1.** Bicarbonate extractable (Colwell) phosphorus (mg/kg) and acid extractable BSES P (mg/kg) taken from 0-10cm depth from Colonsay in Southern Queensland (mean of all nitrogen treatments over various years over three phosphorus application rates).

<table>
<thead>
<tr>
<th>Colonsay P rate</th>
<th>1985</th>
<th>2002</th>
<th>2013*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colwell P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BSES P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>20</td>
<td>nd</td>
<td>62</td>
<td>47</td>
</tr>
</tbody>
</table>

* prior to 2013 0-10cm samples were taken using Stecker & Brown transect (trench) sampling (Lester 2012), not soil cores

**Table 2.** Bicarbonate extractable (Colwell) phosphorus (mg/kg) taken from 0-10cm depth from Tulloona in Northern NSW (mean of all nitrogen application rates over various years over three phosphorus application rates) (Griffiths Bailey & Altman 2010).

<table>
<thead>
<tr>
<th>Tulloona P rate</th>
<th>0-10cm</th>
<th>10-30cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colwell P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BSES P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>19.2**</td>
<td>10.4**</td>
</tr>
<tr>
<td>10</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>48</td>
</tr>
</tbody>
</table>

* prior to 2009 0-10cm samples taken using Stecker & Brown transect sampling (Lester 2012), not soil cores.

** source: Lester 2012

nd indicates no data available PBI=105
At both of these sites, the BFDC-derived critical P level of 22-24mg/kg for a vertosol had been reached by the soil sampling in 2002, some 17 years (and 16 crops) later at Colonsay; and seven years (and 6 crops) later at Tulloona.

Not to say if that they were not at this point before this sampling date.........but from the same starting Colwell P value on two vertosols in the Northern Grains Region, there are two very distinct payback or return on investment (ROI) periods (numeber of years or crops) to spread any fertiliser costs over.

Or to put this another way, from the addition of 160kgP/ha (10P) and 320kgP/ha (20P) at Colonsay for every crop sown since experiment inception until 2002, Colwell P levels have increased 18mg/kg and 52mg/kg respectively up until 2002. Lester (2012) has examined in detail each crop, yield, P removal, nitrogen contribution to yield and P removal, and mass balance status of Colonsay and Tulloona during a similar cropping period. Further, Dowling and Lester (2001) indicate a lower accumulation of Colwell P under high nitrogen rates, presumably because of greater P removal from additional yield produced at the Colonsay site.

If only 5-10% of a crop’s phosphorus is supplied from the surface 0-10cm (which in our environment is generally the driest depth zone of the soil profile and driest for longest), why worry about maintaining greater than critical surface Colwell P values?

Well, it is important to have adequate phosphorus available to emerging wheat crops. Phosphorus deficiency limits wheat grain yield principally by depressing early growth, leaf emergence rate and maximum rate of tiller emergence (Rodriguez et al. 1999).

**Quantifying the value of surface Colwell P**

For paddocks with lower then critical Colwell P in the 0-10cm profile, Bodinaar (2012) identifies that Captial P investments take time and money to build:

- To lift soil P: 2.5kgP per 1 ppm Colwell (PBI < 140)
- 15ppm to 30ppm requires 15 x 2.5 = 37.5 kg P/ha over and above removal
- spread capital P over time, generally 3 - 5 years

Any paddocks with a P value greater than an acceptable critical value (at 90% relative yield) could have a $/ha/P value greater than critical assigned to them.

At these soil P levels, a decision can be made to maintain those surface Colwell P levels, and base this seasons P application rates on P grain removal from the previous season. Or, in some instances, a decision may be made to “mine” the phosphorus in high P paddocks, and divert that intended fertiliser input towards a deep application strategy (if appropriate—see next section) or a different nutrient or muliple nutrients in the same paddock, or somewhere else on the farm.

Clearly additional yield revenue from repeated P applications have had to return *something* on the investment over the example time period, so the rate of return needs to be fully quantified.

**What about Colwell and BSES P at 10-30cm?**

A review of soil data for Tulloona indicates little understanding of subsoil BSES, however a Colwell P value at 10-30cm of 10.4mg/kg is identified by Lester (2012) at the commencement of the experiment in 1996.
Table 3. Bicarbonate extractable (Colwell) phosphorus (mg/kg) and acid extractable BSES P (mg/kg) taken at 10-30cm depth from Colonsay (mean of all nitrogen application rates and each of three phosphorus application rates) 2013

<table>
<thead>
<tr>
<th>Colonsay P rate @ 0-10cm</th>
<th>1985</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Colwell P</td>
<td>BSES P</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>50*</td>
</tr>
<tr>
<td>10</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>20</td>
<td>nd</td>
<td>nd</td>
</tr>
</tbody>
</table>

* 1985 data measured at 10-60cm (Lester 2012)
nd indicates no data available
PBI=157

Soil sampling

Measuring P in the 10-30cm depth layer gives growers and advisers a better understanding of how much phosphorus the plant can access (Bell et al. 2010).

A first step in predicting responses is in understanding what is down there. An investigation of Nutrient Advantage® Laboratory Services (NALS) BSES P soil tests from the past 3 years has seen an approximate 200% increase per year to 2013 in the volume of samples collected. However, the interpretive value of this data is limited given the wide range of soil types, locations, and particularly irregular sampling depths, so few conclusions can be drawn. Still, encouraging to see advisers starting to look at the approach.

There are well documented recommendations and protocols to sample and measure Colwell P in the topsoil (0-10cm) and subsoil (10-30cm) depth layers, to better understand the quantity of plant available P in vertosols of the Northern Grains Region (McLaren at al. 2013).

Interpretation

<table>
<thead>
<tr>
<th>Colwell-P</th>
<th>Surface (0 to 10cm)</th>
<th>&lt;20 to 25mg/kg</th>
<th>Likely to get a response to starter P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&gt;60mg/kg</td>
<td>Ensure good ground cover to limit erosion risk and to avoid nutrient loss in runoff</td>
</tr>
<tr>
<td></td>
<td>BSES P</td>
<td>&lt;25mg/kg</td>
<td>Limited evidence of residual fertiliser accumulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;100mg/kg</td>
<td>High residual fertiliser (cad); slowly available to surface roots</td>
</tr>
</tbody>
</table>

| Subsoil (10 to 30cm) | <10mg/kg | Likely to get a response to deep P placements, unless BSES P high |
|                      | >100mg/kg | Unlikely to see P deficiency in your lifetime |

| BSES P             | <30mg/kg | Limited reserves of slowly available P. Consider replacement of removed P once every five years. |
|                    | >100mg/kg | Potential to slowly replace Colwell-P reserves and support crop growth in large soil volumes |

Figure 6. The surface and subsoil P matrix, developed by Guppy & Bell 2013. Red overlay indicates where the Colonsay site sits within this matrix from indicative soil test values obtained in 2013.
Quantifying soil fertility is one thing, but interpreting it is another. Guidelines have been developed for a starting point (Bell et al. 2014), but critical analysis of the costs and benefits need to be further illustrated, hence the inclusion of deep P strip at Colonsay. It is hoped that given the level of understanding and analysis that has been completed previously at this site (Dowling & Lester 2001), that it may offer more interpretive value for future recommendations.

Management of P nutrition-surface vs deep

Current strategies for P management revolve around a mix of non-agronomic factors including fertiliser pricing, logistics, labour, product type, equipment capacity, planting equipment, fertiliser placement and agronomic factors such as crop potential, crop rotation, 0-10cm soil Colwell P values, fertiliser history, last season crop performance and soil moisture at planting. Where phosphorus fertilisers are used in the NGR, the majority of phosphorus based fertilisers are placed with the seed at planting.

Application of nutrition to below depths normally encountered by our planting machinery requires diligence, investment and ingenuity to efficiently and consistently apply fertiliser amongst the dinosaur bones! Exaggeration, but given the fertiliser cost alone, investment in machinery modification or techniques is paramount to reduce the significant costs associated with this practice.

The complexity of plant responses to subsoil nutrition may suggest that before adopting deep fertiliser practice in a paddock it is essential to understand the effects of edaphic and climatic conditions, soil management, and plant–soil interactions in order to achieve maximum yield benefit (Qifu et al. 2009).

Multiple nutrient, monetary and seasonal interactions

Bell et al. (2014) identify a correlation to economic response of deep-applied nutrients and soil PAWC. This approach certainly makes any interpretative tools that may be developed in the future intuitive to agricultural practitioners, and demonstrates practical understanding of the parameters that determine the economic rate of return.

So when choosing fertiliser product that meet the needs of nutrition required interpreted from your soil tests, select a product or blend that delivers value where multiple nutrients can be applied in one pass (if appropriate).

The responses of winter and summer crops in northern Australia on soils with optimum-to-high nutrients is subject to the rapid and frequent drying of topsoil because of high temperatures and high evaporation demand during the growing season. The pattern of nutrient accumulation by crop species (indeterminate v. determinate) and the mobility of mineral nutrients in the phloem would modify the effectiveness of deep-placed nutrients under drought (Laycock 2014).

Conclusion

It is clear that more research and investigative techniques need to be employed to fully understand the practical implications for farming systems of this approach.

Acknowledgements

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The effectiveness of nitrogen application for protein – 2012 and 2013

Northern Grower Alliance

Key words
Nitrogen, wheat, protein, late nitrogen application

GRDC code
NGA00003: GRDC Grower Solutions for Northern NSW and Southern Qld

Take home messages

1. Foliar application of urea solution provided significant increases in grain protein compared to urea applied by streambar or spread, in a series of eleven trials during 2012 and 2013
2. The level of protein benefit was NOT sufficient to generate a net benefit in any trial
3. Timing differences were less clear, with best results generally from application during late head emergence through to the early milk stage.
4. The highest level of nitrogen recovery in grain protein was 37% in 2012 and 28% in 2013
5. Grain grade price differentials of at least $20-40/t are necessary to warrant foliar application for protein accumulation unless nitrogen recovery can be increased dramatically
6. Assessment of residual soil nitrogen showed total grain and soil recovery from Spread urea was >85% at Weemelah in 2013, despite generally dry conditions following application
7. Application of spread urea at planting provided the most consistent and highest level of grain protein across the dryland sites
8. Targeting nitrogen budgets to maximise yield for soil moisture availability is expected to be more profitable than trying to manipulate protein with late nitrogen application

A frequent issue across the northern region in both 2010 and 2011 was the harvest of wheat at yields well above expectation but with low to very low grain protein levels, not infrequently under 10%. This of course resulted in downgrading at receival and consequently reduced economic returns. Although low protein was evident in a wide range of varieties, EGA Gregory(1) was frequently of concern.

There were a large combination of factors causing the low protein achievement but a clear message from industry was the need to determine whether late application of nitrogen for protein manipulation was an effective management option under northern conditions.

This paper reports on trials conducted in 2012 and 2013, primarily to evaluate the impact of late nitrogen strategies on protein accumulation and to indicate the likelihood of economic benefit.

Primary Aims

1. How effective and economic are late applications of nitrogen for grain protein achievement?
2. Is there an optimal method or timing?
What was done?

A series of eleven application method and timing trials were conducted in southern Qld and northern NSW during the two seasons, with nearly all sites under dryland conditions:

2012 - Inglestone and Bowenville Qld; Tullloona, Croppa Creek, Bellata and Walgett NSW

2013 - Brookstead (irrigated) and Pilton Qld; Weemelah, Tullloona and Narrabri (supplementary irrigation) NSW

All sites evaluated a combination of application methods and timings with urea applied at a standard rate of 40kg N/ha (~87kg urea/ha). This rate was chosen to maximise the likelihood of achieving measureable differences in grain protein. This rate is at the upper end of commercially applied in-crop rates. Three application methods were used:

1. **Spread** - urea simply spread by hand

2. **Streambar** – urea applied in an aqueous solution using BFS streamer bars in 2012 and Chafer streambars in 2013 (Promax 22% urea solution used in 2012 and Ranger 24% in 2013)

3. **Foliar** – urea applied in an aqueous solution using AIXR nozzles in 2012 and TTJ03 nozzles in 2013

All sites had a minimum of four ‘late’ application timings. These timings commenced at ~ full flag leaf emergence (GS39) and then at ~10-14 day intervals. The last timing was generally during dough development (~GS83-87). Table 1 details the level of crop available nitrogen (soil level plus grower fertiliser program) together with the crop growth stages when additional nitrogen was applied. Multiple timings were conducted in an attempt to generate a timing response ‘curve’ for protein accumulation with an expectation that applications ~7-10 days either side of flowering may result in the highest protein content. Yield responses to nitrogen applied at these timings are generally negligible.

Seven of the eleven sites were planted with small plot equipment. At these sites (Bellata and Walgett in 2012 and all sites in 2013) ‘early’ application of spread urea at 40kg N/ha was also evaluated. All these sites evaluated 40 kg N/ha as spread urea applied at planting (IBS), applied at jointing (GS30) or split evenly between the two timings. The remaining four trials in 2012 were conducted in commercially grown crops. All trials investigated the impact of additional nitrogen under conditions where yield and nitrogen supply were believed to be reasonably matched rather than targeting nitrogen deficient situations.

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Crop available nitrogen* kg N/ha</th>
<th>Mean crop growth stage at application</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Inglestone</td>
<td>Not tested</td>
<td>GS39  GS49  GS63  GS76  GS84</td>
</tr>
<tr>
<td></td>
<td>Bowenville</td>
<td></td>
<td>GS41  GS51  GS74  GS78  GS86</td>
</tr>
<tr>
<td></td>
<td>Tullloona</td>
<td></td>
<td>GS39  GS51  GS55  GS65  GS73</td>
</tr>
<tr>
<td></td>
<td>Croppa Creek</td>
<td></td>
<td>GS45  GS59  GS67  GS74  GS85</td>
</tr>
<tr>
<td></td>
<td>Bellata</td>
<td>160 (0-90cm)</td>
<td>GS41  GS51  GS69  GS83  -</td>
</tr>
<tr>
<td></td>
<td>Walgett</td>
<td>70 (0-90cm)</td>
<td>GS39  GS61  GS69  GS83  -</td>
</tr>
<tr>
<td>2013</td>
<td>Brookstead</td>
<td>277 (0-90cm)</td>
<td>GS47  GS61  GS73  GS82  -</td>
</tr>
<tr>
<td></td>
<td>Pilton</td>
<td>147 (0-90cm)</td>
<td>GS39  GS57  GS61  GS85  -</td>
</tr>
<tr>
<td></td>
<td>Weemelah</td>
<td>84 (0-60cm)</td>
<td>GS39  GS60  GS71  GS77  -</td>
</tr>
<tr>
<td></td>
<td>Tullloona</td>
<td>129 (0-60cm)</td>
<td>GS39-41 GS60  GS71-73 GS77-83 -</td>
</tr>
<tr>
<td></td>
<td>Narrabri</td>
<td>141 (0-60cm)</td>
<td>GS39  GS45  GS65  GS73  -</td>
</tr>
</tbody>
</table>

*Crop available nitrogen = total soil mineral N kg/ha (to soil depth) plus fertiliser N kg/ha available across entire trial. It does NOT include any mineralisation credit.

Brookstead double-cropped in cotton stubble with soil mineral N of 16 kg/ha, received 111 kg N/ha at planting and 150 kg...
N/ha top-dressed as urea ~10 days prior to GS30. Yield target at planting 6-7t/ha
GS39 - full flag leaf emergence, GS49 - first awns visible, GS59 - head fully emerged, GS69 - anthesis complete, GS77 - late milk, GS87 - hard dough

Wheat varieties evaluated
EGA Gregory(1) was evaluated for nitrogen response at nine of the eleven sites. Suntop(1) was evaluated at the two irrigated sites in 2013 (Brookstead and Narrabri).

Rainfall
Rainfall quantity and timing at each site, together with any irrigation, is shown in Table 2. Low levels of rainfall were recorded at most sites during August to October in both years. Irrigations at the Brookstead site were well timed following nitrogen application and were expected to provide nearly ‘ideal conditions’ for incorporation and uptake of Timing 1, 2 and 3 applications.

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Timing 1</th>
<th>Timing 2</th>
<th>Timing 3</th>
<th>Timing 4</th>
<th>Timing 5</th>
<th>Total rainfall*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Inglestone</td>
<td>8 mm, +8 days</td>
<td>-</td>
<td>5 mm, +7 days</td>
<td>-</td>
<td>8 mm, +4 days</td>
<td>21 mm</td>
</tr>
<tr>
<td></td>
<td>Bowenville</td>
<td>10 mm, +3 days</td>
<td>-</td>
<td>-</td>
<td>41 mm, +9 days</td>
<td>-</td>
<td>51 mm</td>
</tr>
<tr>
<td></td>
<td>Tulloona</td>
<td>2 mm, +11 days</td>
<td>-</td>
<td>-</td>
<td>9 mm, +5 days</td>
<td>-</td>
<td>15 mm</td>
</tr>
<tr>
<td></td>
<td>Croppa Creek</td>
<td>19 mm, +15 days</td>
<td>-</td>
<td>5 mm, +3 days</td>
<td>15 mm, +6 days</td>
<td>-</td>
<td>39 mm</td>
</tr>
<tr>
<td></td>
<td>Bellata</td>
<td>-</td>
<td>1 mm, +11 days</td>
<td>5 mm, +4 days</td>
<td>16 mm, +3 days</td>
<td>NA</td>
<td>21 mm</td>
</tr>
<tr>
<td></td>
<td>Walgett</td>
<td>11 mm, +8 days</td>
<td>-</td>
<td>2 mm, +2 days</td>
<td>-</td>
<td>NA</td>
<td>12 mm</td>
</tr>
<tr>
<td>2013</td>
<td>Brookstead</td>
<td>38 mm, +8 days</td>
<td>7 mm, +9 days</td>
<td>3 mm, +6 days</td>
<td>1 mm, +3 days</td>
<td>NA</td>
<td>65 mm rainfall</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 mm, +3 days</td>
<td>30 mm, +3 days</td>
<td>30 mm, +2 days</td>
<td></td>
<td></td>
<td>150 mm irrigation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 mm, +5 days</td>
<td>-</td>
<td>-</td>
<td>+13 days</td>
<td>-</td>
<td>34 mm</td>
</tr>
<tr>
<td></td>
<td>Pilton</td>
<td>10 mm, +8 days</td>
<td>2 mm, +13 days</td>
<td>5 mm, +2 days</td>
<td>10 mm, +10 days</td>
<td>NA</td>
<td>30 mm irrigation</td>
</tr>
<tr>
<td></td>
<td>Weemelah</td>
<td>-</td>
<td>19 mm, +7 days</td>
<td>8 mm, +8 days</td>
<td>-</td>
<td>NA</td>
<td>27 mm</td>
</tr>
<tr>
<td></td>
<td>Tulloona</td>
<td>-</td>
<td>22 mm, +6 days</td>
<td>8 mm, +7 days</td>
<td>-</td>
<td>NA</td>
<td>29 mm</td>
</tr>
<tr>
<td></td>
<td>Narrabri</td>
<td>-</td>
<td>19 mm, +5 days</td>
<td>6 mm, +7 days</td>
<td>30 mm, +2 days</td>
<td>-</td>
<td>25 mm</td>
</tr>
</tbody>
</table>

Eg at the Inglestone site, 8 mm of rain were recorded 8 days after Timing 1, there was no rain between Timing 2 and 3 with 5 mm received 7 days after Timing 3.

* Total rainfall = amount recorded between the Timing 1 application and 14 days after the last application.
All irrigation quantities and timings are shown in bold.
Site characterisation – yield and protein

Figure 1 shows the yield and protein levels of untreated grain at each site. Yields ranged from ~2 to 5t/ha in both years but with the majority of sites >3t/ha. Protein levels were low to very low in 2012, ranging from 8.8 to 11.8% with increased levels in 2013, ranging from 11.2 to 14.3%.

![Figure 1. Yield and protein content of untreated grain at individual sites](image)

Late season nitrogen application - key results

Leaf scorch

The only treatment that caused any noticeable leaf burn or scorch was urea applied as an aqueous solution through a conventional nozzle (Foliar treatment). However the level of damage was not concerning at any site or application timing in this series of trials (the only concerning level of leaf scorch occurred in a separate trial in 2013 with UAN application at 40 kg N/ha).

Yield

There was a significant impact on yield recorded in only one of the eleven trials. At Weemelah 2013, the application at ~GS60 resulted in a significant yield benefit compared to both the GS39 and GS77 timings. Although statistically significant, the absolute level of yield benefit was only ~100 kg/ha. The GS60 application received a 19mm rainfall event, seven days after application.

Protein

All sites were analysed individually with an overall analysis also conducted for both years. Figures 2 and 3 show the comparison of the three applications methods (across all timings) and the comparison of timings (across all application methods) over both years.

Test weight and screenings

There was no clear impact from nitrogen application method or timing on test weight or screening level in any trial.
In both years, foliar application resulted in a significant increase in protein compared to either spread or streambar for late season application timings. Foliar application resulted in significant benefits at two individual sites in both 2012 and 2013.

The largest protein benefit in 2012 was obtained at Tulloona using foliar application at GS51 (1.2% but NSD). In 2013 the largest benefit was obtained at Weemelah using Foliar application at GS71 (0.8%, signif).
Nitrogen recovery in grain

The nitrogen recovery in grain was calculated for all treatments (yield t/ha x protein % x 1.75). Figures 4 and 5 show the comparison of the three applications methods (across all timings) and the comparison of timings (across all application methods) over both years.

**Figure 4.** Mean nitrogen recovery in grain from addition of 40 kg N/ha, six sites 2012
Treatments that share the same letter within the groups of methods or timings are not significantly different at p=0.05
Broken line indicates the mean nitrogen recovery in grain of untreated control (no additional nitrogen)

**Figure 5.** Mean nitrogen recovery in grain from addition of 40 kg N/ha, five sites 2013
Treatments that share the same letter within the groups of methods or timings are not significantly different at p=0.05
Broken line indicates the mean nitrogen recovery in grain of untreated control (no additional nitrogen)
Overall in 2012, foliar application resulted in a significant increase in nitrogen recovery in grain compared to either spread or streambar but still only recovered a mean of ~3 kg N/ha from the 40 kg N/ha applied. In 2013 there was no significant benefit overall from foliar application compared to the other methods although there was a non-significant trend to foliar recovering an extra 4 kg N/ha compared to the untreated control. Foliar application resulted in significant benefits at three of six individual sites in 2012 but only one of five in 2013.

The largest nitrogen recovery in grain benefit in 2012 was obtained at Croppa Creek using foliar application at GS45 (15 kg N/ha, signif). In 2013 the largest benefit was obtained at Weemelah using Foliar application at GS60 (9 kg N/ha, signif). The efficiency of conversion of applied nitrogen to harvested protein was disappointing in both seasons. The mean of the highest recovery treatments in each trial in 2012 was 21% (range 6 to 37%) and also 21% in 2013 (range 12 to 28%).

**How effective was early season application of Spread urea?**

Application of the equivalent amount of spread urea at planting or GS30 (or split between the two timings) was evaluated at six sites. The spread urea at planting was incorporated by sowing (IBS). The mean response to spread urea at all timings is shown in Figures 6 and 7.

![Mean % protein from addition of 40 kg N/ha Spread urea, applied at varied crop stages, two trials 2012](image)

NSD, P=0.10

**Figure 6.** Mean % protein from addition of 40 kg N/ha Spread urea, applied at varied crop stages, two trials 2012

Broken line indicates the mean % protein of untreated control (no additional nitrogen), IBS=incorporated by sowing operation
Figure 7. Mean % protein from addition of 40 kg N/ha Spread as urea, applied at varied crop stages, five trials 2013.

Treatments that share the same letter are not significantly different at p=0.05. 
Broken line indicates the mean % protein of untreated control (no additional nitrogen), IBS=incorporated by sowing operation.

The early application of spread urea resulted in equivalent or higher protein levels than spread applications later in the season. Across all dryland sites, urea spread and incorporated by sowing resulted in either the highest or second highest protein level of all treatments.
Did treatments perform better under irrigation?

The trial at Brookstead was planted on the 19th June with flowering commencing the 3rd week of September. It received five 30 mm irrigations during the crop development from GS47 to GS73 (over a period of 31 days). In addition it received 38 mm of rain during head emergence. Figures 8, 9 and 10 show the impact of nitrogen application on protein and nitrogen recovery, together with the protein impact from spread urea.

**Figure 8.** % protein from addition of 40 kg N/ha under irrigation, Brookstead 2013
Treatments that share the same letter within the groups of methods or timings are not significantly different at p=0.05
Broken line indicates the mean % protein of untreated control (no additional nitrogen)

**Figure 9.** Nitrogen recovery in grain from addition of 40 kg N/ha under irrigation, Brookstead 2013
Treatments that share the same letter within the groups of methods or timings are not significantly different at p=0.05
Broken line indicates the mean nitrogen recovery in grain of untreated control (no additional nitrogen)
Figure 10. Nitrogen recovery in grain from addition of 40 kg N/ha spread as urea applied at varied crop stages, Brookstead 2013

Treatments that share the same letter are not significantly different at p=0.05
Broken line indicates the mean nitrogen recovery in grain of untreated control (no additional nitrogen), IBS=Incorporated By Sowing operation

The results at the irrigated site were very disappointing with the best treatment only increasing grain protein in Suntop (1) by 0.5% with the highest level of actual nitrogen grain recovery only 28%. The poor grain recovery may have been influenced by the high background nitrogen (13.7% protein in the untreated), however three other varieties achieved 15-16% protein in the same trial with no additional nitrogen application.

**Was the remainder of the late applied nitrogen lost?**

At the Weemelah site there was sufficient rain post-harvest to sample for nitrogen to a soil depth of 30cm in early December. The soil was dry below this depth and it was considered unlikely that nitrogen would have moved any deeper by this stage. Soil samples were taken from the untreated and all methods of application at Timing 2 (GS60) and Timing 4 (GS77). Timing 2 was selected as this was the most effective application with 19mm of rain received 7 days after application. Timing 4 had the lowest level of impact and only experienced a total of 11mm of rain in the six weeks following application with a single rain event occurring 15 days after application. Figure 11 shows the level of grain and soil recovery of nitrogen expressed as a % of the total applied.
Although the nitrogen grain recovery from spread urea was significantly poorer than the foliar application, there were very high levels of recovery of soil nitrogen from spread applications for both timings. This indicated that ‘losses’ from these applications were low despite the absence of follow-up rain for at least 7 days following either application. No assessment was made of the amount of nitrogen captured in leaf and stubble material. The partial nitrogen recovery (grain and soil) from streambar and foliar application was significantly lower than from spread urea but the remaining nitrogen may have been lost by volatilisation, captured in plant material or most probably a combination of both.

Economics

Economic comparisons were conducted on all individual treatments where there was a significant difference in either yield or protein content compared to the untreated. Table 3 shows the highest net benefit treatments from the four sites where significant yield or protein differences occurred.

**Table 3. Economic analysis of the highest net benefit treatments**

<table>
<thead>
<tr>
<th>Site</th>
<th>Treatment</th>
<th>Receival grade</th>
<th>Gross benefit</th>
<th>Fertiliser and application cost</th>
<th>Net benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Croppa Creek 2012</td>
<td>Foliar GS45</td>
<td>No change ASW</td>
<td>$69/ha</td>
<td>$84/ha</td>
<td>-$15/ha</td>
</tr>
<tr>
<td>Weemelah 2013</td>
<td>Foliar GS60</td>
<td>APW to H2 (+$9/t)</td>
<td>$77/ha</td>
<td>$84/ha</td>
<td>-$7/ha</td>
</tr>
<tr>
<td>Tullona 2013</td>
<td>Foliar GS71-73</td>
<td>No change HPS1</td>
<td>$79/ha</td>
<td>$84/ha</td>
<td>-$5/ha</td>
</tr>
<tr>
<td>Narrabri 2013</td>
<td>Foliar GS69+</td>
<td>No change HPS1</td>
<td>$27/ha</td>
<td>$84/ha</td>
<td>-$57/ha</td>
</tr>
</tbody>
</table>

Granular urea $552/t ($48/ha @ 40 kg N), Urea solution $0.46/L ($76/ha @ 40 kg N/ha)
Application costs: spread $25/ha, foliar $8/ha
Grain prices: 2012 ASW $237, 2013 HPS1 $251, APW $256, H2 $265
Although there was a small but significant increase in protein from foliar application, late nitrogen application did not provide a net economic benefit in any of these eleven trials.

Table 4 shows the grain price differential needed to generate a return on investment of 1 ($1 net benefit for every $1 spent), under a range of nitrogen recovery in grain efficiencies and varying protein increase targets.

**Table 4**. Minimum grain price differential required to achieve a $1 net benefit for every $1 spent

<table>
<thead>
<tr>
<th>% protein increase required/targeted</th>
<th>% nitrogen recovery in grain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20%</td>
</tr>
<tr>
<td>0.5%</td>
<td>$20/t</td>
</tr>
<tr>
<td>1.0%</td>
<td>$36/t</td>
</tr>
<tr>
<td>2.0%</td>
<td>$70/t</td>
</tr>
</tbody>
</table>

Urea solution $7.90/L ($1.90 kg N/ha)
Application cost: foliar $8/ha
Assuming 5t/ha yield (grain price differentials will increase by ~$2-3/t at 3t/h yields

The data from these two ‘unfavourable’ years only resulted in mean nitrogen recovery in grain of ~20%. Under these conditions, a grain price differential of at least $36/t would have been needed if a 1% increase in protein was required and the grower was content with a $1 net benefit for every $1 spent. For late nitrogen application to be a more viable consideration, consistent and high % nitrogen recovery in grain (40-60%) combined with grain price differentials of at least $10-20/t would be needed.

**Discussion**

1. **Method comparison**

With generally low levels of rainfall in both years, it was not surprising that spread and streambar application were ineffective in increasing protein. For these methods to provide a benefit, nitrogen must be both successfully incorporated into the soil but also reach a depth where roots are actively foraging. These approaches appear much more suited to early season application or use in years with frequent rainfall during spring.

**Foliar** application resulted in significant protein increases compared to the spread and streambar methods. This strongly suggest that leaf uptake, in late season application, is capable of significantly increasing grain protein levels. However the magnitude of impact was generally disappointing. The highest recovery from any foliar treatment in 2012 was 15 kg N/ha (mean across all sites 6 kg N/ha, range 0 to 15 kg N/ha). In 2013 the highest recovery from any foliar treatment in 2012 was 11 kg N/ha (mean across all sites 7 kg N/ha, range 4 to 11 kg N/ha).

2. **Timing comparison**

The impact from application timing was less apparent than expected. The clearest result was that application at late milk to mid dough resulted in significantly lower protein than from early applications. This was significant in all four trials where significant timing differences occurred. The data from these trials was inconclusive in determining an optimal growth stage for application although the highest protein result was achieved from application during late head emergence to early milk at seven of the eleven sites.

3. **Nitrogen recovery**

The efficiency of conversion of applied nitrogen to protein was disappointing in both seasons. The highest level of recovery of any treatment was 37% in 2012 and 28% in 2013 with ~20% nitrogen recovery more realistic across all sites. The level of recovery in 2012 was particularly disappointing as
grain protein levels in the untreated were below 12% in all trials. Under these nitrogen limited situations, the recovery was expected to be much higher.

4. Spread urea

Urea applied at planting (IBS) generally provided the highest protein result of all Spread applications. Although early application of additional nitrogen can cause canopy management issues, these results (in years with erratic or low spring rainfall) support the need to get nitrogen on early. In-crop applications are likely to have more benefit in seasons with more frequent and reliable spring rainfall.

5. Irrigated results

The pattern of results for method and timing of application was similar to the overall pattern at dryland sites but the protein and nitrogen recovery in grain levels were extremely disappointing. The best individual treatment result was a recovery of 28% but the mean of all treatments was only 8%. There is no explanation for the lower efficiencies recorded in this trial.

Conclusions

This extensive set of trials was hampered by the low rainfall experienced during the springs of 2012 and 2013, however it clearly showed that:

1. Significant increases in protein can be gained by late nitrogen application
2. The level of increase however was not sufficient to deliver economic benefits
3. Foliar was clearly the most effective method of application
4. Timing differences were less clear but generally supported application between late head emergence and early milk stages when targeting protein accumulation
5. Although late application of spread urea was, as expected, the least effective method, the results from soil coring at two trials indicated a high level of recovery in the 0-30cm samples (one trial not presented in this paper). This supported recent results from Graeme Schwenke, NSW DPI, indicating nitrogen volatilisation from urea application in-crop may not be as high as previously considered.

These results suggest that trying to increase wheat protein with late nitrogen application is unlikely to be a very effective management tool in areas where spring rainfall is highly erratic. Unless nitrogen in grain recovery levels can be increased dramatically, grain price differentials of ~$20-40/t are probably necessary before even considering this type of approach. Supply of nitrogen requirements either prior to or at planting, or as a top up during early crop growth stages would appear a much more reliable and effective strategy. Economic benefits from nitrogen application targeting yield potential are likely to be far easier to achieve than when targeting protein increases.

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1 Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.
Managing nitrogen for yield and protein: 2013 update

Rohan Brill, Matthew Gardner, Greg Brooke, Leigh Jenkins, Bruce Haigh and Guy McMullen, NSW DPI Tamworth and Trangie

Key words
Nitrogen, yield, protein, varieties

GRDC code
DAN0169: Variety Specific Agronomy Packages

Take home messages
- Crop N requirement depends on water-limited yield potential, targeted grain protein and crop management (disease, supply of other nutrients, weed control and sowing time).
- When choosing varieties, consider long term yield and protein results for your region, disease resistance/tolerance packages and target grades.
- In 2013 variety choice played a significant role in final grain yield and grain protein concentration, which influenced the capacity to achieve APH.
- Profitable production is driven not only by yield but is also influenced by quality targets and the cost to achieve them. Growers and advisors need to consider the economic cost:return and risks of targeting/achieving APH
- The recovery of applied N in grain can be low with residual soil mineral N levels only accounting for a portion of the unrecovered N.

Introduction
The Variety Specific Agronomy Packages project has been conducting trials since 2007 to evaluate the agronomic management of near release and recently released varieties. This has included trials to test variety responses to applied nitrogen. There have been a number of papers presented at previous GRDC Updates on the key factors that determine N supply and demand in crops. This paper presents new results from 2012 and 2013 from trials on N management. These trials have studied N responses across a range of wheat varieties that have shown adaptation for the northern grain region including improved disease resistance – especially to stripe rust and Pratylenchus thornei.

It is always important to remember that the most important factors that influence yield and protein are location affects (soil water, in-crop rainfall, disease and nutrient supply). When determining application strategies for N fertiliser and appropriate varieties, growers and advisors need to consider the factors listed above as well as target markets.

Soil mineral nitrogen (N) levels and associated grain protein concentrations have generally declined in northern soils over the past five years, largely due to the removal of N in grain (above average yields from 2010-2012 in both summer and winter crops) but also due to potential losses from denitrification in wet seasons. Despite the low soil N levels, the recovery of applied fertiliser N has generally been only low to moderate. For example in six VSAP trials across the northern region in 2012, the apparent efficiency of applied N (N harvested in grain/N applied) ranged from 6.5 % at a high N rate at Spring Ridge to 42.5 % from a low N rate at Trangie. This poses the question - what is the fate of the N that is not harvested in grain?

Strong et al. (1996) reported N recoveries ranging from 39-49% from studies on nitrogen application to irrigated wheat in the Darling Downs region. The recovery of applied N in grain of the subsequent crop ranged from 2 to 6 % and declined further in both the third and fourth crops, resulting in a total

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N recovery (in grain) of 56 % over four seasons. The authors hypothesised that the remaining N could either be remaining in the soil (potentially in mineral form or immobilised into organic form) or may have been lost through denitrification.

2013 trial details

Following on from nitrogen management trials that were conducted in 2010, 2011 and 2012 seven trials were established in 2013 across northern NSW. Starting mineral (nitrate plus ammonium) nitrogen levels ranged from 80 to 290 kg N/ha and starting soil water from 30 to 185 mm (Table 1).

<table>
<thead>
<tr>
<th></th>
<th>Garah</th>
<th>Terry Hie Hie</th>
<th>Rowena</th>
<th>Pine Ridge (Wong)</th>
<th>Wongarbon (Wong)</th>
<th>Merriwa</th>
<th>Trangie (TARC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sowing Date</td>
<td>29/4/13</td>
<td>27/5/13</td>
<td>28/5/13</td>
<td>6/6/13</td>
<td>29/5/13</td>
<td>16/5/13</td>
<td>9/5/2013 (dry)</td>
</tr>
<tr>
<td>Available N at sowing (kg N to 120 cm)</td>
<td>80</td>
<td>93</td>
<td>80</td>
<td>100</td>
<td>290</td>
<td>215</td>
<td>80</td>
</tr>
<tr>
<td>Plant available water at sowing (mm)</td>
<td>81</td>
<td>175</td>
<td>185</td>
<td>-</td>
<td>50</td>
<td>120</td>
<td>30</td>
</tr>
<tr>
<td>In-Crop Rainfall (mm)</td>
<td>140</td>
<td>123</td>
<td>48</td>
<td>95</td>
<td>265</td>
<td>150</td>
<td>205</td>
</tr>
<tr>
<td>Predicta B - Crown Rot</td>
<td>Low</td>
<td>Low</td>
<td>Nil</td>
<td>-</td>
<td>Nil</td>
<td>High</td>
<td>Nil</td>
</tr>
<tr>
<td>Predicta B – RLN</td>
<td>Low (Pt)</td>
<td>Nil</td>
<td>Low (Pt)</td>
<td>-</td>
<td>Low (Pn) Med (Pt)</td>
<td>Nil</td>
<td>Low (Pn)</td>
</tr>
</tbody>
</table>

Treatments

In 2013 all trials had 6 common entries. These were the bread wheat varieties; LongReach Dart\(^l\), EGA Gregory\(^l\), LongReach Spitfire\(^l\), Sunguard\(^l\), Suntop\(^l\) and Sunvale. At the Pine Ridge, Terry Hie Hie, Garah and Rowena sites the durum wheat variety Caparo\(^l\) and the bread wheat variety Livingston\(^l\) were also included.

At each trial site there were two components to the nitrogen treatments. Firstly, four N rates applied as urea at sowing (0, 40, 80 and 160 kg N/ha) and secondly split N application of 80 kg N applied at sowing and/or at stem elongation (GS30) (data not presented in this paper).

Results

2013 nitrogen x variety trials

Across-site analysis

Across-site analysis was conducted to determine the contribution of trial factors (trial site, nitrogen rate and variety) to grain yield, grain protein concentration and grain nitrogen yield across the 2013 trials (Table 1). The factors site, N rate and variety collectively accounted for 89%, 76% and 85% of the variation in grain yield, grain protein concentration and gain N yield respectively. Further separation of these effects showed that site effects had the greatest impact, followed by N rate and finally variety choice on grain yield and grain N recovery. Site and N rate accounted for the greatest proportion of variation in protein followed by variety. These results underline the need to firstly consider site effects, especially starting water and soil N, followed by considering the appropriate fertiliser management strategy and thirdly considering variety choice.
Table 2. Contribution of site effects, applied N (kg N/ha) and variety to variation in grain yield, protein and grain N recovery across seven sites in 2013

<table>
<thead>
<tr>
<th>Factors</th>
<th>Grain Yield</th>
<th>Protein</th>
<th>Grain N Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>0.75</td>
<td>0.25</td>
<td>0.63</td>
</tr>
<tr>
<td>Site + Nrate</td>
<td>0.77</td>
<td>0.49</td>
<td>0.72</td>
</tr>
<tr>
<td>Site + Nrate + Variety</td>
<td>0.79</td>
<td>0.63</td>
<td>0.76</td>
</tr>
<tr>
<td>Site * Nrate * Variety</td>
<td>0.89</td>
<td>0.76</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Nitrogen Responses

Significant yield responses to applied N were measured at three of the seven trial sites – two positive and one negative (Figure 1). At Pine Ridge and Terry Hie Hie there was a significant response to each level of applied N. At Trangie the only significant response was a yield reduction at the highest N rate compared to the untreated control. The sites that responded positively were both relatively high yielding and had starting soil nitrogen levels < 100 kg N/ha.

Figure 1. Effect of N rate (kg/ha) on grain yield averaged across six varieties at seven sites in 2013 (Means within sites followed by the same letter are not significantly different at P=0.05)

The responsive sites at Pine Ridge and Terry Hie Hie also had a significant interaction between variety and applied N (Figure 2). At Pine Ridge the higher applications of N increased yield for EGA Gregory, Suntop and Spitfire whereas the other lines reached maximum yield at 80 kg N/ha. At Terry Hie Hie, EGA Gregory and Suntop had higher yields at 160 kg N/ha compared to other lines which had maximum yields at 80 kg N/ha, while Sunvale was not responsive to applied N at this site.
Figure 2. Effect of N rate and variety on grain yield at Pine Ridge (top) and Terry Hie Hie (bottom) in 2013

With respect to grain protein concentration, all sites were responsive to additional N (Figure 3). At Wongarbon, the site with the highest starting N, all treatments (including the control with no added N) achieved grain protein concentration >13%. At all other sites additional N was required to achieve 13% protein when averaged across all varieties. There was a significant interaction between N rate and variety at Terry Hie Hie and Rowena.

If targeting protein ≥13%, the application of 160 kg N/ha at Pine Ridge failed to meet this level when averaged across varieties. At the other responsive yield site at Terry Hie Hie 160 kg N/ha was required to achieve 13% protein. At Rowena, Garah and Trangie the application of 40 kg N/ha was required to achieve 13% protein. Merriwa required between 40 - 80 kg N/ha to achieve 13% protein.
At Variety where Suntop four 106 Variety 5% Sunvale Suntop Sunguard Spitfire Livingston EGA Dart Caparoi GRDC Dart concentration This Pine protein exception trials value (Means LSD 0.001 0.14 0.007 0.001 0.22 0.16)

Figure 3. Effect of N rate on grain protein at seven sites in 2013
(Means within sites followed by the same letter are not significantly different at P=0.05)

Variety
At all seven sites in 2013 there was a significant effect of variety on yield, grain protein concentration and grain nitrogen recovery (GNR). The best performing varieties for grain yield were Dart(l), EGA Gregory(l), Suntop(l) and Spitfire(l). EGA Gregory(l) was in the highest yielding group at four of seven sites while Dart(l), Suntop(l) and Spitfire(l) in three of seven sites (Table 3).

Table 3. Effect of variety (averaged across N rates) on grain yield at seven sites in 2013
(Means within sites followed by the same letter are not significantly different at P=0.05)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Pine Ridge</th>
<th>Terry HH</th>
<th>Rowena</th>
<th>Garah</th>
<th>Merriwa</th>
<th>Wong</th>
<th>Trangie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capari(l)</td>
<td>3.88 c</td>
<td>3.13 d</td>
<td>3.81 a</td>
<td>2.16 a</td>
<td></td>
<td></td>
<td>2.92 de</td>
</tr>
<tr>
<td>Dart(l)</td>
<td>3.94 bc</td>
<td>3.55 b</td>
<td>3.67 ab</td>
<td>2.01 b</td>
<td>2.73 a</td>
<td>4.14 a</td>
<td></td>
</tr>
<tr>
<td>EGA Gregory(l)</td>
<td>4.44 a</td>
<td>3.52 b</td>
<td>3.67 ab</td>
<td>2.51 a</td>
<td>2.14 b</td>
<td>3.89 bc</td>
<td>3.38 a</td>
</tr>
<tr>
<td>Livingston(l)</td>
<td>4.05 b</td>
<td>3.39 c</td>
<td>3.55 bc</td>
<td>2.25 b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spitfire(l)</td>
<td>4.32 a</td>
<td>3.53 b</td>
<td>3.47 c</td>
<td>2.52 a</td>
<td>2.80 a</td>
<td>3.91 bc</td>
<td>3.19 b</td>
</tr>
<tr>
<td>SunGuard(l)</td>
<td>4.02 bc</td>
<td>3.47 b</td>
<td>3.56 bc</td>
<td>2.55 a</td>
<td>2.17 b</td>
<td>4.04 ab</td>
<td>3.03 ed</td>
</tr>
<tr>
<td>SunTop(l)</td>
<td>4.30 a</td>
<td>3.89 a</td>
<td>3.55 bc</td>
<td>2.51 a</td>
<td>2.14 b</td>
<td>3.88 bc</td>
<td>3.12 bc</td>
</tr>
<tr>
<td>Sunvale</td>
<td>3.99 bc</td>
<td>3.08 d</td>
<td>3.25 d</td>
<td>2.51 a</td>
<td>1.64 c</td>
<td>3.70 c</td>
<td>2.85 e</td>
</tr>
<tr>
<td>P value</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.007</td>
<td>0.001</td>
</tr>
<tr>
<td>5% LSD</td>
<td>0.14</td>
<td>0.11</td>
<td>0.16</td>
<td>0.24</td>
<td>0.31</td>
<td>0.22</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Variety also had a consistent impact on grain protein across all sites in 2013 (Table 4). At most sites protein levels were close to APH receival standards of 13% when averaged across N treatments. The exception to this was Pine Ridge where no variety achieved APH protein levels. As was seen in 2012 trials Spitfire(l) had consistently higher grain protein concentration across all sites – even those sites where it was the highest yielding variety. Spitfire(l) achieved APH protein levels at six of seven sites. This contrasts with the other high yielding lines EGA Gregory(l), which achieved APH at one site, and SunTop(l) which failed to achieve APH at any of the sites in these trials.
Table 4. Effect of variety (averaged across N rates) on grain protein concentration at seven sites in 2013

Means within sites followed by the same letter are not significantly different at P=0.05

<table>
<thead>
<tr>
<th></th>
<th>Pine Ridge</th>
<th>Terry HH.</th>
<th>Rowena</th>
<th>Garah</th>
<th>Merriwa</th>
<th>Wong</th>
<th>Trangie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caparoi(l)</td>
<td>11.9</td>
<td>11.9</td>
<td>13.4</td>
<td>13.7</td>
<td>12.2</td>
<td>12.6</td>
<td>13.1</td>
</tr>
<tr>
<td>Dart(l)</td>
<td>11.9</td>
<td>12.1</td>
<td>13.3</td>
<td>14.3</td>
<td>12.8</td>
<td>13.3</td>
<td>12.5</td>
</tr>
<tr>
<td>EGA Gregory(l)</td>
<td>10.9</td>
<td>11.4</td>
<td>12.7</td>
<td>12.1</td>
<td>12.8</td>
<td>13.3</td>
<td>12.5</td>
</tr>
<tr>
<td>Livingston(l)</td>
<td>11.6</td>
<td>11.9</td>
<td>12.8</td>
<td>13.9</td>
<td>13.5</td>
<td>12.8</td>
<td>13.3</td>
</tr>
<tr>
<td>Spitfire(l)</td>
<td>12.3</td>
<td>12.2</td>
<td>14.5</td>
<td>14.0</td>
<td>13.5</td>
<td>14.6</td>
<td>14.1</td>
</tr>
<tr>
<td>Sunguard(l)</td>
<td>11.3</td>
<td>11.8</td>
<td>12.7</td>
<td>12.7</td>
<td>13.2</td>
<td>13.5</td>
<td>12.6</td>
</tr>
<tr>
<td>Suntop(l)</td>
<td>11.4</td>
<td>11.3</td>
<td>12.7</td>
<td>12.8</td>
<td>12.4</td>
<td>12.8</td>
<td>12.3</td>
</tr>
<tr>
<td>Sunvale</td>
<td>12.1</td>
<td>12.9</td>
<td>13.5</td>
<td>13.3</td>
<td>14.5</td>
<td>14.6</td>
<td>13.4</td>
</tr>
</tbody>
</table>

P value: 0.001  0.001  0.001  0.001  0.001  0.007  0.001
5% LSD: 0.5     0.4     0.3     0.4     0.6     0.2     0.2

At Terry Hie Hie and Rowena there was a significant interaction between N rate and varietal protein levels (Figures 4 and 5 respectively). At Terry Hie Hie, Spitfire(l) and Sunvale had similar protein responses to increasing N rates and achieved higher protein levels at each N increment compared to EGA Gregory(l), Sunguard(l) and Suntop(l). EGA Gregory(l) and Suntop(l) had greater yield increases at higher N rates at this site compared to the other varieties (Figure 2). Despite protein differences between Spitfire(l) and Sunvale at the high end and EGA Gregory(l), Sunguard(l) and Suntop(l) at the low end, the rate of protein response to applied N was similar for each of these five varieties. Dart(l) responded differently to these varieties, having similar protein levels to Spitfire(l) and Sunvale where nil N was applied but with a smaller increase in grain protein with increasing N rate.

Figure 4. Effect of N rate and variety on grain protein at Terry Hie Hie in 2013

At Rowena, which did not have a yield response to additional N, Spitfire(l) had significantly higher grain protein concentration (achieving APH1) at all N application rates compared with all other varieties. Sunvale was the most responsive (in terms of grain protein concentration) to added N at this site.
Figure 5. Effect of N rate and variety on grain protein at Rowena in 2013

The grain N recovery (GNR), calculated from the total yield and protein, also showed significant differences between varieties in 2013. At all sites Spitfire(l) had the highest GNR while the performance of the other high yielding lines was more variable (Table 5).

Table 5. Effect of variety on grain N recovery in 2013

<table>
<thead>
<tr>
<th></th>
<th>Pine Ridge</th>
<th>Terry HH.</th>
<th>Rowena</th>
<th>Garah</th>
<th>Merriwa</th>
<th>Wong.</th>
<th>Trangie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caparov(l)</td>
<td>83 bc</td>
<td>66 d</td>
<td>89 a</td>
<td>52 cd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dart(l)</td>
<td>83 bc</td>
<td>76 b</td>
<td>85 b</td>
<td>50 d</td>
<td>58 b</td>
<td>91 bcd</td>
<td>67 c</td>
</tr>
<tr>
<td>EGA Gregory(l)</td>
<td>87 b</td>
<td>71 c</td>
<td>81 c</td>
<td>53 cd</td>
<td>48 cd</td>
<td>90 cd</td>
<td>74 b</td>
</tr>
<tr>
<td>Livingston(l)</td>
<td>84 bc</td>
<td>71 c</td>
<td>79 cd</td>
<td>55 bcd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spitfire(l)</td>
<td>95 a</td>
<td>82 a</td>
<td>88 ab</td>
<td>62 a</td>
<td>66 a</td>
<td>100 a</td>
<td>78 a</td>
</tr>
<tr>
<td>Sunguard(l)</td>
<td>80 c</td>
<td>72 c</td>
<td>79 cd</td>
<td>56 bc</td>
<td>50 c</td>
<td>95 ab</td>
<td>67 c</td>
</tr>
<tr>
<td>Suntop(l)</td>
<td>87 b</td>
<td>77 b</td>
<td>79 cd</td>
<td>56 bc</td>
<td>46 cd</td>
<td>87 d</td>
<td>67 c</td>
</tr>
<tr>
<td>Sunvale</td>
<td>86 b</td>
<td>70 c</td>
<td>77 d</td>
<td>58 ab</td>
<td>41 d</td>
<td>94 bc</td>
<td>67 c</td>
</tr>
<tr>
<td>P value</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>5% LSD</td>
<td>5.0</td>
<td>2.9</td>
<td>3.4</td>
<td>5.0</td>
<td>6.7</td>
<td>4.7</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Means within sites followed by the same letter are not significantly different at P=0.05

At the yield responsive sites at Pine Ridge and Terry Hie Hie there was also a significant interaction between variety and N rate for GNR (Figure 6). Varieties with higher GNR at higher N levels were EGA Gregory(l), Spitfire(l) and Suntop(l). At the lower N rates Spitfire had higher GNR compared to most other lines.
To determine the portion of applied N that is available in mineral form to the subsequent crop, EGA Gregory plots in three VSAP N trials from 2012 were soil cored to a depth of 90 cm in autumn 2013. These trials were analysed for mineral N availability (nitrate and ammonium) and then calculated into a kg/ha basis assuming a bulk density at all sites of 1.4 g/cm³. At Forbes and Wagga Wagga there were four N treatments applied – nil, 50 kg/ha at sowing, 50 kg/ha at sowing followed by 50 kg/ha at Z31 and 50 kg/ha at sowing followed by 100 kg/ha at Z31. At Coonamble there were three N treatments applied, all at sowing – nil, 50 and 100 kg N/ha.

The N accounted for in grain in these trials was generally low. The highest recovery was at Forbes with 26% of the 50 kg/ha N rate at sowing recovered in the grain at harvest (Table 6).
Table 6. Recovery of N (%) in grain (harvest 2012) and in soil (cored autumn 2013) following N application (kg N/ha) to EGA Gregory at Forbes, Wagga Wagga and Coonamble in 2012

<table>
<thead>
<tr>
<th>Fertiliser recovery</th>
<th>Forbes 2012 N rate (kg/ha) and timing</th>
<th>Wagga Wagga 2012 N rate (kg/ha) and timing</th>
<th>Coonamble 2012 N rate (kg/ha) and timing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50 sow</td>
<td>50 sow + 100 Z31</td>
<td>50 sow</td>
</tr>
<tr>
<td>Accounted N in grain</td>
<td>13</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>N Uptake from sowing N</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>N Uptake from Z31</td>
<td>9</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>Accounted N in soil</td>
<td>2</td>
<td>45</td>
<td>81</td>
</tr>
<tr>
<td>Residual N from sowing</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Residual N from Z31</td>
<td>43</td>
<td>78</td>
<td>11</td>
</tr>
<tr>
<td>Unaccounted N</td>
<td>35</td>
<td>33</td>
<td>42</td>
</tr>
<tr>
<td>Unaccounted from sowing</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Unaccounted N from Z31</td>
<td>-2</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

At Forbes there was a high recovery (soil and grain) of the N that was applied at Z31, calculated to be 100% and 93% for the 50 and 100 kg/ha rates respectively; but there was only a low recovery of the 50 kg/ha N rate applied at sowing (30%). The N application at sowing at Forbes was done to soil that was at field capacity and followed by rain causing waterlogging that may have led to denitrification.

The Wagga Wagga results were in direct contrast to the Forbes results, as the total recovery (grain and soil) from the 50 kg/ha N rate at sowing was 84%, but the recovery from the Z31 applications of 50 and 100 kg/ha N was 26% and 40% respectively. The free draining soil type at Wagga Wagga is generally not conducive to waterlogging so denitrification from sowing would have been less of an issue than at Forbes.

The recovery of N in grain and soil at Coonamble was 26% and 41% of the 50 and 100 kg/ha N applications at sowing.

Location of residual nitrogen in the soil profile

The trial sites were each cored in four separate soil depth segments; 0-10 cm, 10-30 cm, 30-60 cm and 60-90 cm. At Forbes and Coonamble (Figure 7) the residual nitrogen from 2012 applications was generally only found in the 0-10 and 10-30 cm layers, with no significant effect of N application evident in the 30-60 and 60-90 cm. This would likely be due to the low rainfall received after mid-July in 2012.
At Wagga there was a trend for the residual N to be found at all segments of the soil profile (Figure 8). The Wagga site was a well drained soil type and these tests showed that the applied N moved down through the profile to at least 90 cm.

**Figure 8.** Mineral N at four separate soil depth segments in autumn 2013 following four N application treatments at Wagga Wagga in 2012

**Conclusions**

There were strong effects of site, N application and varietal choice on yield, protein and grain N recovery in 2013. Site and N application were strong determinants of these factors with variety having a smaller but still important role.

There was generally a low grain recovery of applied N in VSAP trials in 2012. When the mineral N in the soil was also accounted for, the recovery of N ranged from 26% to 84% and averaged approximately 48%.
Although these trials show that a portion of unused N may be available to the subsequent crop, the amount of N that is available to be recovered is generally significantly less than the difference between N applied and N recovered in grain. The reasons for this are unclear from these trials, but there are several possible explanations that could all contribute to the low N recovery, including:

- Nitrogen unaccounted for in the straw.
- Immobilisation (conversion of nitrogen to organic form) – this would likely have occurred to some degree at all sites.
- Denitrification – most likely at the Forbes site from the N treatments applied at sowing. Unlikely to be a major cause at Wagga Wagga (well drained soil) or Coonamble (insufficient rainfall).
- Leaching – unlikely to be a major cause at Forbes and Coonamble, but potentially a cause at Wagga.
- Volatilisation – possible at all sites, but previous research in Northern NSW by Schwenke et al. has shown that losses in winter cropping are not major.

There are often trade-offs for N management in northern farming systems, as in-crop rainfall is generally variable and unreliable for N application; however the application of high rates of N at sowing can be risky in economic and agronomic terms.

Management factors to increase nitrogen efficiency in the region include:

- Increasing the area of crop planted to grain legumes in order to supply N in a slower release organic form that is less prone to denitrification.
- Match N inputs to water availability and crop yield potential.
- Avoid the application of N prior to rainfall events that may cause waterlogging, especially in environments that may be prone to flooding.

Acknowledgments

The Variety Specific Agronomy Project (DAN00169) is a partnership between NSW DPI and GRDC. The trials would not have been possible without the valuable input of growers and advisors at each location. The trials and data collection were managed by Stephen Morphett, Jayne Jenkins, Jim Perfrement, Patrick Mortell, Peter Formann, Jan Hoskings and Rod Bambach (all NSW DPI).

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Reviewed by:

Dr Steven Simpfendorfer

Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.
Nitrogen in wheat 2013: effect of applied and residual nitrogen on yield and the economics of chasing protein. What happened at “Colonsay” on the Darling Downs & “Myling” Tulloona, in Northern NSW?

Bede O’Mara, Incitec Pivot Fertilisers, Toowoomba

Key words
Nitrogen, Colonsay, Tulloona, long term experiments, crop nutrition, agronomy, soil testing, nitrogen use efficiency, fertilisers, economics

GRDC code
The research presented here is entirely funded by Incitec Pivot Fertilisers.

Take home messages

<table>
<thead>
<tr>
<th></th>
<th>Colonsay</th>
<th>Tulloona</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>All N rates gave a significant response over control, but no differences between N treatments (40N, 80N, 120N)</td>
<td>No response to N (high background soil N site). No N fertiliser applied since 2004.</td>
</tr>
<tr>
<td>Protein</td>
<td>Positive grain protein correlation with increasing N rate (0N @9.45% and 120N @ 12.57%).</td>
<td>No response to N. There is a significant negative protein response to increasing P rates, but all protein grades were at APH quality.</td>
</tr>
<tr>
<td>Screenings</td>
<td>No differences observed.</td>
<td>No differences observed in response to N.</td>
</tr>
<tr>
<td>WUE</td>
<td>Significant difference vs 0N 0P where both N &amp; P rates are increased</td>
<td>NSD.</td>
</tr>
<tr>
<td>Risk vs Reward</td>
<td>Generally negative returns from fertiliser applied in 2013 season. Best (break even) rate is 40N.</td>
<td>No N fertiliser applied due to high background nitrogen availability.</td>
</tr>
<tr>
<td>Summary</td>
<td>Older cultivation with a track record of N response - long fallowed from Wheat in 2011, with moderate starting soil nitrogen produced a reasonable crop yield, but despite the tight finish, protein was generally &lt;13%.</td>
<td>Newer cultivation long fallowed from a failed millet cover crop in 2011/12. High starting soil nitrogen, coupled with a below average season capped yield and drove high proteins.</td>
</tr>
</tbody>
</table>

# Risk: Reward calculated using net $ returns / fertiliser cost

Product key 2013
Urea 46% N
ENTEC® Urea 46% N + nitrification inhibitor DMPP
Triple Superphosphate (TSP) 20.1%P; 1.0%S; 13.5%Ca
Gran-Am® 20.2% N; 24.0% S
Background

The “Colonsay” long term experiment in the Formartin district of Queensland’s Darling Downs was established in 1985 by Incitec Fertilisers to study the long term impacts of ongoing fertiliser use on land that was first cultivated for cropping in the 1940’s. In the 29th year, Colonsay is one of the longer running agricultural experiments in Australia.

During this time, twenty-two crops (summer and winter cereals and pulses) have been harvested, with an additional 3 failed crops (2 chickpea and 1 sorghum crop) that were sown but not harvested.

Four N rates (0N, 40N, 80N & 120N) as Urea across four P rates (0P, 5P, 10P & 20P) as TSP are examined at Colonsay with four S rates (0S, 10S, 20S & 30S as Gran-Am®) added as a split plot design on the 80N 10P treatment.

A companion site at “Myling” in the Tulloona district of Northern New South Wales was established some 10 years later, in 1996, to provide a comparison between this younger (first cultivated around 1994) site to crop responses to applied fertiliser in an older soil at “Colonsay”.

The “Myling” site has produced 15 summer and winter cereals and pulse crops during its 18 year tenure as a long term trial, with little response to N over later years, largely due to higher starting soil N and higher mineralisable N potential. Significant responses to applied N were observed in the first 6 crops over 5 years under a high frequency opportunity rotation.

Five N rates* (0N, 30N, 60N, 90N & 120N) and three P rates (0P, 10P & 20P) have been investigated at Tulloona. NOTE: No additional N fertiliser has been applied at Tulloona since 2004 to run down residual soil nitrogen.

Application timing (AS at sowing or PS pre-plant) has been examined previously at Colonsay, between 1985-1995, with no significant differences observed (Lester 2012).

Product comparisons of anhydrous ammonia (BIG N® 82%N) and Urea have been compared at the Tulloona site (1996-2004), with no significant differences observed between either product Lester 2012).

Methods 2013

Colonsay:

Fallow soil sampling in March 2013 for nitrogen also revealed RLN populations ~4068 P. thornei /kg @ 0-10cm, or greater than threshold (Thompson et al 2009).

Pre-plant fertiliser treatments (N as urea & S as Gran-Am®) were applied in early May 2013, on 50cm rows, using small plot equipment.

EGA Gregory/1 wheat was sown on 35 cm rows at 57kg/ha with P treatments drilled with seed on 4 June 2013.

Harvest occurred on 14 November 2014.

GSR from planting to harvest was 144mm.

Tulloona:

Fallow soil sampling in March 2013 for nitrogen also revealed RLN populations ~2862 P. thornei /kg @ 0-10cm, or greater than threshold (Thompson et al 2009).

No pre-plant N fertiliser treatments were applied in 2013.

LongReach Spitfire/1 wheat was sown on 25 cm rows at 45kg/ha with P treatments drilled with seed on 24 June 2013.

Harvest occurred on 14 November 2014.
GSR from planting to harvest was 102mm.

Results & Discussion

Colonsay

Figure 1. The effect of N rate on wheat yield and protein at Colonsay, 2013

Yield

Nitrogen application between 0 and 40 kgN/ha significantly increased mean wheat yield from 3.87 t/ha to 4.18 t/ha. There were no further yield responses from additional N application at 80N (4.22 t/ha) and 120N (4.12 t/ha).

This modest response to nitrogen is thought to be a consequence of residual N in the profile. Following a two year long fallow, mineral N profiles were only assessed using composite samples from the control (0N 0P) and 80N (10P & 20P) treatments to a depth of 90cm. Starting soil nitrogen for 0N was 68 kgN/ha and for 80N treatments were similar at 98 to 103 kgN/ha). While the true position of starting soil nitrogen between N treatments cannot be ascertained, at 80N there was an extra 30 to 35 kgN/ha mineral N available over and above fertiliser N application.

Table 1. Colonsay 2013 Wheat grain yield (kg/ha corrected to 12% moisture)

<table>
<thead>
<tr>
<th>N rate (kg/ha)</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.87</td>
</tr>
<tr>
<td>40</td>
<td>4.05</td>
</tr>
<tr>
<td>80</td>
<td>4.14</td>
</tr>
<tr>
<td>120</td>
<td>3.97</td>
</tr>
</tbody>
</table>

LSD (p=0.05) 0.246 (N x P); LSD (p=0.05) 0.128 (N rate)

Protein

Nitrogen application increased mean wheat grain protein significantly at all rates. The first 40 kgN application increased mean protein by over a percentage point (1.15%) and similarly with the second 40 kgN/ha (0.98%) for the 80N treatment. However, a further 40 kgN/ha (120N treatment) increased protein by only 0.38%, and well below APH grade (13% protein) despite no further yield response.

Grain N recovery (yield x protein% x 1.75) was 68.1, 81.9, 90 and 90.6 kgN/ha for 0, 40, 80 and 120N treatments. Starch deposition is more sensitive to moisture stress than protein deposition during
grain fill (Herridge, 2013). With screenings (pinched grain) only in the 2.3 to 3.1% range, there may have been factors other than water stress responsible for the modest protein response at 120N. While crop disease can reduce N supply for grain fill, crown rot was the only notable disease and levels were lower for N treatments (3.1-4.4% white heads for 80N & 120N) than the control (7.5% white heads). Further examination of residual soil N and stubble N content may shed further light.

Table 2. Colonsay 2013 grain protein % (corrected to 11% moisture)

<table>
<thead>
<tr>
<th>P rate (kg/ha)</th>
<th>N rate (kg/ha)</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10.6</td>
<td>11.8</td>
</tr>
<tr>
<td>5</td>
<td>10.1</td>
<td>10.9</td>
</tr>
<tr>
<td>10</td>
<td>9.6</td>
<td>10.9</td>
</tr>
<tr>
<td>20</td>
<td>10.0</td>
<td>11.3</td>
</tr>
<tr>
<td>mean</td>
<td>10.05</td>
<td>11.20</td>
</tr>
</tbody>
</table>

LSD (p=0.05) 0.531 (N x P); LSD (p=0.05) 0.284 (N rate)

Water Use Efficiency

WUE for all treatments had a site range of 11.0 kg/mm upto 12.7 kg/mm, which is within documented ranges for the Northern grains Region (Dalgliesh & Foale 1998). WUE was significantly higher for all rates of N compared with the control, but not significantly different between N rates.

Table 3. Colonsay 2013 wheat WUE (kg/mm)

<table>
<thead>
<tr>
<th>P rate (kg/ha)</th>
<th>N rate (kg/ha)</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11.47</td>
<td>11.95</td>
</tr>
<tr>
<td>5</td>
<td>11.07</td>
<td>12.69</td>
</tr>
<tr>
<td>10</td>
<td>10.98</td>
<td>12.22</td>
</tr>
<tr>
<td>20</td>
<td>12.24</td>
<td>12.54</td>
</tr>
<tr>
<td>mean</td>
<td>11.44</td>
<td>12.35</td>
</tr>
</tbody>
</table>

LSD (p=0.05) 0.7265 kg/mm (N x P); LSD (p=0.05) 0.3791 kg/mm (N rate)

Screenings

There were no significant differences in screenings with all treatments <5%, so marketable without quality dockage or discount.

Economics of nitrogen application

Grain quality grades and prices achieved:
(source: Estimated Eastern pool return 2013/14 AWB Pool less freight and handling)

- ASW (<10.5% protein) @ $274/t
- APW (10.5-11.5% protein) @ $282/t
- H2 (>11.5% protein) @ $294/t

Table 4. Colonsay 2013-Returns net of control and fertiliser cost ($/ha)

<table>
<thead>
<tr>
<th>P rate (kg/ha)</th>
<th>N rate (kg/ha)</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>48.6</td>
<td>31.1</td>
</tr>
<tr>
<td>5</td>
<td>50.1</td>
<td>81.4</td>
</tr>
<tr>
<td>10</td>
<td>-14.2</td>
<td>35.1</td>
</tr>
<tr>
<td>20</td>
<td>-23.2</td>
<td>-47.4</td>
</tr>
<tr>
<td>mean</td>
<td>15.32</td>
<td>25.05</td>
</tr>
</tbody>
</table>
Table 5. Colonsay 2013-Risk / reward ratio (net $ returns / fertiliser cost)

<table>
<thead>
<tr>
<th>P rate (kg/ha)</th>
<th>0</th>
<th>40</th>
<th>80</th>
<th>120</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>1.06</td>
<td>0.34</td>
<td>-0.48</td>
<td>0.05</td>
</tr>
<tr>
<td>5</td>
<td>-4.45</td>
<td>0.76</td>
<td>0.73</td>
<td>-0.01</td>
<td>-0.74</td>
</tr>
<tr>
<td>10</td>
<td>-2.22</td>
<td>-0.17</td>
<td>0.27</td>
<td>-0.25</td>
<td>-0.59</td>
</tr>
<tr>
<td>20</td>
<td>-0.73</td>
<td>-0.18</td>
<td>-0.28</td>
<td>-0.53</td>
<td>-0.43</td>
</tr>
<tr>
<td>mean</td>
<td>-1.45</td>
<td>0.37</td>
<td>0.26</td>
<td>-0.32</td>
<td>-0.23</td>
</tr>
</tbody>
</table>

Risk vs Reward Assumptions: N @ $1.15/kgN & P @ $3.98/kgP

Using our assumptions for grain price and fertiliser cost, the highest yielding treatment (80N/5P) delivers the highest return net of fertiliser cost. However, where risk:reward ratio is considered, a lower yielding, lower cost treatment (40N:0P) provides the best outcome per dollar invested despite generating around $30/ha less overall. While driven by yield, the economic analysis may be strongly influenced by grade – for this particular season only moderate to small premiums were on offer for high protein milling wheat due to a shortage of feed grains.

Tulloona

Nitrogen effect on yield and protein

This site has not been responsive to nitrogen application for some time. Nitrogen treatments have not been applied since 2004 due to high background levels of residual profile N, although chickpeas were grown in 2010 as a break crop and would have contributed further N across all treatments from a 2 t/ha crop. Prior to sowing the 2010 crop, total soil N (0-90cm) was 95, 121, 166, & 384 kgN/Ha for 0, 30, 60 & 120 N rate treatments. Limited planting opportunities and continuing dry seasonal conditions have made it difficult to ‘mop-up’ residual profile N in this soil type with a much younger cultivation.

Figure 2. Effect of N rate on wheat yield and protein at Tulloona, 2013
Yield

In 2013, dry seasonal conditions limited mean wheat yield to 2.8 t/ha with no statistical differences between N treatments.

**Table 6.** Tulloona 2013 wheat grain yield (t/ha corrected to 12% moisture) -NSD

<table>
<thead>
<tr>
<th>P rate (kg/ha)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>2.75</td>
<td>2.69</td>
<td>2.71</td>
<td>2.73</td>
<td>2.60</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>3.04</td>
<td>2.63</td>
<td>2.86</td>
<td>2.83</td>
<td>2.87</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>2.82</td>
<td>2.83</td>
<td>3.02</td>
<td>2.78</td>
<td>2.88</td>
</tr>
<tr>
<td>mean</td>
<td>20</td>
<td>2.87</td>
<td>2.72</td>
<td>2.86</td>
<td>2.78</td>
<td>2.78</td>
</tr>
</tbody>
</table>

LSD (p=0.05) 0.349 (N x P); LSD (p=0.05) Not significant (N rate)

Protein

There were no differences in mean wheat protein levels in response to N rate. High grain protein, lack of yield response and modest screenings (pinched grain) indicate an adequate N supply under dry seasonal conditions.

**Table 7.** Tulloona 2013 wheat grain protein (at 11% moisture)-NSD

<table>
<thead>
<tr>
<th>P rate (kg/ha)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.1</td>
<td>15.1</td>
<td>15.2</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>14.8</td>
<td>14.9</td>
<td>14.9</td>
<td>14.6</td>
<td>14.9</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>14.7</td>
<td>14.8</td>
<td>14.7</td>
<td>14.8</td>
<td>14.8</td>
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<tr>
<td>mean</td>
<td>20</td>
<td>14.8</td>
<td>14.9</td>
<td>14.9</td>
<td>14.8</td>
<td>15.0</td>
</tr>
</tbody>
</table>

LSD (p=0.05) 0.3% (N x P)

Screenings

There were no differences in screenings (3.8 to 4.2% range) in response to N rate in 2013.

Water Use Efficiency

WUE did not differ between N treatments which is not surprising given the lack of yield response. Mean WUE for 0, 30, 60, 90 and 120N were 14.22, 13.56, 14.17, 13.76 and 13.78 kg/mm respectively.

Risk vs Reward

Since nitrogen was not applied in 2013, and all grain protein levels were above marketable bin grade, and additionally with high grain protein being indicative that yield remains water-limited rather than N-limited, further financial analysis was not undertaken.

Conclusion

Results from 2013 raise issues of managing for different N scenarios in different seasons. The need to account for cultivation age, residual soil N & soil moisture is highlighted. The variable that is most difficult to manage is growing season rainfall and temperature during flowering and grain fill.

Findings from the long term trials endorse a strategic approach of matching soil N supply with crop N requirement based on critical protein target to minimise the chances of not optimising yield in a good season. Following this strategy will increase the likelihood of growing APH grades in poor to average seasons. Implementation of such a strategy will depend on a range of variables including rotation and cultivation age.
Strategic management of N to achieve the above goals may involve incorporation of pulse crops into the rotation particularly on older cultivation and a willingness to invest in N when cash flow allows while also keeping an eye on N resources using suitable diagnostics.

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**References**


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Key nitrogen loss pathways and strategies to minimise losses

By Charlie Walker, Technical and Development Manager, Incitec Pivot Fertilisers

There is some confusion about the loss mechanisms for nitrogen from cropping systems and strategies for minimising these losses. Confounding the issue is the desire by farmers and advisors to know the “average losses”. Unfortunately in biological systems with numerous variables, working on the average simply isn’t going to cut it!

The first thing to consider is that there are temporary losses and permanent losses.

In cropping systems the relevant temporary loss is immobilisation or nitrogen tie-up. This occurs when nitrogen is applied to a system where the carbon:nitrogen ratio exceeds about 25:1. Where cereal stubble is incorporated, the C:N ratio will often be 80:1 or more.1

While there is concern about immobilisation, it can be a good thing if nitrogen is tied up and held with decaying organic material and then released back to the crop the following spring during the peak nitrogen demand period. Unfortunately, this kind of excellent timing can not be relied upon.

Permanent losses are of greater concern. These are:

- Leaching – movement of nitrate nitrogen below the root zone
- Volatilisation – loss of gaseous ammonia to the atmosphere
- Denitrification – loss of gaseous nitrous oxide or nitrogen gas to the atmosphere.

The confusion is often with the gaseous losses, so let’s be clear.

Volatilisation losses occur under two broad scenarios:

- Where urea is surface applied, it reacts with water (hydrolysis) to form unstable ammonium carbonate which then converts to ammonia (gas), ammonium nitrogen and carbon dioxide. The ratio of ammonia:ammonium determines the potential for volatilisation losses – the higher the pH in the reaction zone, the greater potential for volatilisation. There is another factor required for ammonia loss – air movement. Where urea is applied to a dense crop canopy with limited air movement, ammonia gas may largely stay in the canopy where it can be absorbed by leaves.

- If ammonium sulphate is surface applied where significant free lime (calcium carbonate) is present at the surface, then production of unstable ammonium carbonate can also occur.

Denitrification can occur once nitrogen is present in the soil in the nitrate form. Under limited oxygen conditions, soil microbes can use nitrate as an oxygen source resulting in nitrous oxide release. While nitrous oxide is recognised as a potent greenhouse gas, the proportion of nitrogen lost from most cropping systems in this form is usually negligible (in the order of 0.05 to 0.4% of nitrogen applied – Barton et al 2010; Grace pers. comm). There are exceptions, with higher losses reported from the high rainfall zone in southern Australia where soil organic carbon levels are higher (Harris et al 2013).
In cropping systems, more significant denitrification losses can occur under waterlogged conditions, in particular where water ponds at the surface for extended periods and on warm soils. Under these conditions, it is not unusual for 30% of nitrate nitrogen to be lost (Chen et al 2008).

So, what can be done to minimise these losses?
When battling the environment, no approach will ever be perfect. However, a simple framework can help.

Choice of product
Urea is the cropping product of choice, but there are alternatives like:
- Green Urea NV™ which is treated with a urease inhibitor to minimise volatilisation losses
- ENTEC® Urea which is treated with a nitrification inhibitor to hold nitrogen in the stable ammonium form, while not denying crops access to nitrogen
- EASY N® - liquid urea ammonium nitrate which has half its nitrogen in the ammonium nitrate form and therefore is less susceptible to volatilisation.

Rate
Ensure that excess nitrogen is not applied. To do this, look at profile soil testing and nitrogen budgeting using a reputable NATA accredited ASPAC compliant lab like Nutrient Advantage® and a Fertcare accredited decision support system like Nutrient Advantage Advice.

Application technique
Placing urea under the ground will minimise volatilisation losses.

Timing
Split application of nitrogen is often advocated as a way of managing both production and loss risk. Surface application of urea just before significant rainfall can assist in moving the nitrogen into the soil and away from the risk of volatilisation.

Minimising the risk of denitrification losses is a bit more complex. If you can manage to avoid having high nitrate levels when waterlogging events are likely, particularly while soils are warm, then you are probably doing the best you can to manage this risk.

Nitrogen loss pathways

References: