BFDC Interrogator concurrent session

BFDC Interrogator – a new tool for exploring soil test critical levels and crop responsiveness in broad acre crops

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Key words
nutrient, calibration, database, critical value, %RY, nitrogen, phosphorus, potassium, sulphur

GRDC code
DAQ 00183, DAN 00166

Take home message
Have you ever wondered about the origins of soil test critical levels for N, P, K and S for broadacre crops and wanted to explore or validate critical ranges for your soil types, locality and circumstances? This is now possible by way of a web-tool developed with GRDC funding called the Better Fertiliser Decision for Cropping in Australia (BFDC) Interrogator. The database underlying the BFDC Interrogator contains the results of more than 5000 soil test calibration experiments conducted in Australia since the 1950s. Fertiliser decisions made by grain growers and their advisers should all start with, and rely on, objective knowledge of the fertility status of paddocks. The BFDC Interrogator provides information about soil test critical levels for the four nutrients that frequently account for 20-30% of variable crop production costs - N, P, K and S.

BFDC interrogator training is now online at www.bfdc.com.au.

Attendance at the workshop sessions will let you explore the response database, provide participants with the information to help gain unlimited access to BFDC Interrogator and involve discussion about concepts of crop nutrition and crop nutrition research.

GRDC continue to invest in BFDC, including an online data entry tool, inclusion of long term trials and N, P, K and S research trials to fill gaps in knowledge

Background

The Making Better Fertiliser Decisions for Cropping Systems in Australia project (BFDC) aims to provide the fertiliser industry, agency staff and agribusiness advisors and farmers with knowledge and resources to improve nutrient recommendations for optimising crop production. The BFDC database is a national database of historical fertiliser response data for the main grain crops grown in Australia. BFDC is recognised by the Fertiliser Industry Federation of Australia as the best available data for supporting the decision tools that fertiliser industry members use as the basis for interpretation of soil tests and formulating recommendations.

Fertiliser decisions made by grain growers and their advisers should all start with, and rely on, objective knowledge of the fertility status of paddocks. These decisions need to account for the nutrient requirements of plants for growth, nutrient availability in soils, and nutrient losses that can occur during crop growth (e.g. de-nitrification or erosion).

Making better decisions about soil nutrient management and crop nutrition starts with gaining an understanding of how soil fertility fits into the whole crop production process. The BFDC Interrogator provides information about soil test critical levels for the four nutrients that frequently account for 20-30% of variable crop production costs - N, P, K and S.
For an overview of the development, processes, research findings and relevance of the BFDC see the following paper


BFDC Interrogator

Soil test-crop response (N, P, K and S fertiliser) trials have been undertaken by many different organisations in Australia since the late 1950's. As new soil tests were developed, soil test criteria (defining soil test values at near optimum or maximum yield for a specific crop) were developed for interpreting the nutrient status of cropping soils for growers.

Trial results have been recorded in scientific publications, project reports, extension publications (e.g. regional trial report books) or field and office archives. Commonly, experimental designs varied from trial to trial and hence different amounts of data were collected and reported.

All of the relevant soil test-crop response data that could be obtained for each trial have been entered into the BFDC database. Up to 50 % of the trials conducted during the period were unable to be used in the database as a result of poor design (e.g. nutrient rate not sufficient to define Ymax) or a lack of data essential for interpretation (e.g. records of associated soil test and depth). Interestingly the database is dominated (60%) by responses of wheat to N and P, highlighting limited data are available for current cropping systems and varieties. The value of the dataset and lessons learnt from it is explored in the following paper


A web application namely, BFDC interrogator provides access to the BFDC database, allowing registered users to query the data held in the BFDC database so that soil test-crop response relationships and critical soil test values based on specified criteria (e.g. a cropping region or soil type) can be derived for different crops.

A soil test-crop response calibration for a specific crop type (e.g. wheat) is the relationship between the measured yield increase to an applied nutrient at a range of experimental sites and the soil test value for each trial site.

Researchers have commonly used the percent relative yield (% RY) (either as grain yield or crop biomass yield at flowering or crop maturity) as the estimate of yield responsiveness, largely because this estimate partially circumvents variations in yield responses to applied nutrient between sites and to variations in seasonal conditions that could affect grain yield and/or yield responsiveness to an applied nutrient.

The BFDC Interrogator generates critical soil test values for N, P, K and S. The figure below shows all soil test – crop response records for Colwell P and wheat.
Figure 1. Output from a BFDC Interrogator query for P (Colwell) calibration in wheat, including all records in the BFDC database.

The critical soil test level (and the variance, called the critical range) is defined at near maximum relative yield. The BFDC Interrogator determines the critical soil test criterion at 80, 90 and 95% RY. These associated trial data collected has been recorded against the response and can be partitioned to better define the critical soil test level according to factors such as:

- Geographic location
- Soil types or soil texture classes.
- Crop descriptors (e.g. crop type).
- Environmental characteristics (e.g. growing season rainfall).
Soil test – crop response

There have been a number of scientific publications (Crop & Pasture Science Special Issue, Volume 64) derived from the trial data contained within the BFDC dataset. These papers explore soil test – crop response relationships and critical soil test values for N, P K and S around selected parameters including location, crop type and rainfall.

**Nitrogen**


**Phosphorus**


**Potassium**


**Sulfur**


**BFDC training**

Significant work has been undertaken to roadtest the training. Validation of training methodologies and the course content can be viewed in the following paper.

Dowling CW, Speirs SD (2013) An extension perspective—increasing the adoption of more reliable soil test interpretation. http://dx.doi.org/10.1071/CP13216

The face to face training has been taken to an online self paced interactive form. Gaining access to the BFDC Interrogator is possible by undertaking a half day face to face or self-paced online familiarisation course that ensures users are aware of the intended uses, limitations and statistical rules, and to ensure the outputs of an interrogation of the database is reliable and fit for purpose. Generally the face to face and online courses would take 4 – 6 hours to complete. By attending the BFDC Interrogator sessions to be held during the concurrent sessions at the GRDC Adviser Updates at Coonabarabran and Goondiwindi in 2014, you will have reduced the time to complete the training to as little as 1 - 1.5 hours.

**References**


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- Pythium
- Smuts
- Bunt
Nutrition concurrent session

The effectiveness of nitrogen application for protein – 2012 and 2013

Richard Daniel, Rachel Norton, Anthony Mitchell, Linda Bailey and Rob Duncan,
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 message

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(t) 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; Tulloona, Croppa Creek, Bellata and Walgett NSW

2013 - Brookstead (irrigated) and Pilton Qld; Weemelah, Tulloona 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 measurable 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></td>
<td></td>
<td></td>
<td>Timing 1</td>
</tr>
<tr>
<td>2012</td>
<td>Inglestone</td>
<td>Not tested</td>
<td>GS39</td>
</tr>
<tr>
<td></td>
<td>Bowenville</td>
<td></td>
<td>GS41</td>
</tr>
<tr>
<td></td>
<td>Tulloona</td>
<td></td>
<td>GS39</td>
</tr>
<tr>
<td></td>
<td>Croppa Creek</td>
<td></td>
<td>GS45</td>
</tr>
<tr>
<td></td>
<td>Bellata</td>
<td>160 (0-90cm)</td>
<td>GS41</td>
</tr>
<tr>
<td></td>
<td>Walgett</td>
<td>70 (0-90cm)</td>
<td>GS39</td>
</tr>
<tr>
<td>2013</td>
<td>Brookstead</td>
<td>277 (0-90cm)</td>
<td>GS47</td>
</tr>
<tr>
<td></td>
<td>Pilton</td>
<td>147 (0-90cm)</td>
<td>GS39</td>
</tr>
<tr>
<td></td>
<td>Weemelah</td>
<td>84 (0-60cm)</td>
<td>GS39</td>
</tr>
<tr>
<td></td>
<td>Tulloona</td>
<td>129 (0-60cm)</td>
<td>GS39-41</td>
</tr>
<tr>
<td></td>
<td>Narrabri</td>
<td>141 (0-60cm)</td>
<td>GS39</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 was evaluated for nitrogen response at nine of the eleven sites. Suntop 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 2. Rainfall quantity and interval following nitrogen application timings

<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, +4 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, +9 days</td>
<td>4 mm, +5 days</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>30 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, +7 days</td>
<td>30 mm, +2 days</td>
<td></td>
<td></td>
<td>150 mm irrigation</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>34 mm</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>NA</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%.

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.

![Graph showing nitrogen recovery in grain](image_url)

**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)

![Graph showing nitrogen recovery in grain](image_url)

**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)

**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 19\textsuperscript{th} June with flowering commencing the 3\textsuperscript{rd} 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 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 $7.90/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

Figure 11. % nitrogen grain and soil recovery for late application methods at GS60 and GS77, Weemelah 2013
Treatments that share the same letter are not significantly different at p=0.05
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></td>
<td>$12/t</td>
</tr>
<tr>
<td></td>
<td>$9/t</td>
</tr>
<tr>
<td>1.0%</td>
<td>$36/t</td>
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<tr>
<td></td>
<td>$20/t</td>
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<tr>
<td></td>
<td>$14/t</td>
</tr>
<tr>
<td>2.0%</td>
<td>$70/t</td>
</tr>
<tr>
<td></td>
<td>$36/t</td>
</tr>
<tr>
<td></td>
<td>$25/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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Acknowledgements

Our thanks to the large number of growers and agronomists involved in these trials, to David McRae, Yara Nipro for the provision of fertiliser samples and to Pacific Seeds and AGT for seed requirements. Thanks also to Graeme Schwenke for edits and comments.

Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.
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:

Nitrogen management in wheat - getting more grain per dollar of nitrogen applied. The economics of chasing protein and issues of NUE and timing

Jim Laycock, Incitec Pivot Fertilisers

Key words
Nitrogen, Economics, Protein, NUE, Timing

Take home messages
Aim to maximise yield response first when budgeting for seasonal nitrogen.
Protein responses to the application of nitrogen from GS40 to GS61 are more reliable where yield is already maximised.

Product key
- Urea 46% N
- Easy N (UAN) 32% N w/w or 42.5% w/v
- PCU – polymer coated urea 3 month release pattern – 43% N
- Entec® Urea – urea treated with nitrification inhibitor DMPP – 46% N
- GreenNV – urea treated with a urease enzyme inhibitor NBPT – 46%N

Curban Enhanced N 2013

Figure 1. Gregory sown into lupin stubble, on a Red Sodosol on the 17th May with reasonable soil moisture. Site management and statistical analysis by Kalyx with the co-operation of C&S Roche, “Reedsdale” Curban. GSR 180mm

Observations
- Basal application of 12N/24P per hectare as Granulock Z (11%N:22%P:4%S:1%Zn).
- There were no screenings >2% at any nitrogen rate.
- All grain sample weights were >75kgs/hectolitre
- No significant response in plot grain yield to product type, placement, rate or timing of application.
• Significant grain protein response to 30kgs/ha/N (12.6%) over the 12kgs/ha/N (11.5%) applied with Granulock Z at plant
• Significant protein response to 60kgs/ha/N (13.6%) over 30kgs/ha/N (12.6%) applied at plant
• No significant difference in protein between 90kgs/ha/N (14.1%) and 120kgs/ha/N (14.8%)
• Significant protein response with 120kgs/ha/N (14.8%) over 60kgs/ha/N (13.6%) applied at plant
• No significant difference in grain protein when 50% of the N was applied at plant and 50% applied as a topdressing at GS31.
• When 60kgs/ha/N and 90kgs/ha/N was applied at planting and 25kgs/ha/N applied at GS59 as urea or Easy N there was a significant grain protein response at the 60kgs/ha/N and 25kgs/ha/N rate over the urea top dressed treatment when Easy N was applied through streamer nozzles.
• There was no significant difference in grain protein for the PCU treatments at 60kgs/ha/N (12.7%) over the 30kgs/ha/N (12.6%) applied at plant. All other treatments (apart from the control) were significantly greater than the PCU treatments. At 13.6% the urea plus Entec treatment, grain protein was significantly better than the PCU treatments.

Conclusions
A minimum of least 60kgs/ha/N of additional N was required to move grain plot yields of 3.5t/ha above 13% protein at the Curban site. With all nitrogen rate treatments up to 120kgs/ha/N screenings were less than 5%.

A combination of the 2013 wheat grade pricing and low yields due to below average growing season rainfall resulted in a lack of economic response to applied nitrogen in this trial. As is often the case where yield potential is below average it is difficult to justify the additional cost of nitrogen to move wheat quality to higher grades without a significant yield response as well.

Enhanced N Forbes 2013

Figure 2. Suntop wheat sown into canola stubble on Red Kandosol on the 26th of May with good soil moisture. Sown by Kalyx using the IPF cone seeder with the co-operation of Chris Morrison, Forbes. Trial management and statistical analysis by Kalyx. GSR 283mm
Observations

- Basal application of 12N/24kgs/ha/P as Granulock Z.
- There were no screenings >2% at any nitrogen rate.
- All grain sample weights were >75kgs/hectolitre
- Significant plot grain yield and/or grain protein responses to product type, placement, rate and timing of application.
- No significant plot grain yield response to 30kgs/ha/N applied banded below and to the side of the plant line at planting (4.50t/ha) over the control (4.54t/ha). Significant protein response to 30kgs/ha/N (8.8%) over the control (8.2%)
- Significant plot grain yield response to 60kgs/ha/N (5.11t/ha) over the 30kgs/ha/N (4.50t/ha). Significant grain protein response to 60kgs/ha/N (10%) over the 30kgs/ha/N (8.8%)
- No significant plot grain yield response with 90kgs/ha/N (5.38t/ha) and 120kgs/ha/N (5.34t/ha) over the 60kgs/ha/N (5.11t/ha). Significant grain protein response to 90kgs/ha/N (11.1%) and 120kgs/ha/N (11.7%) over 60kgs/ha/N (10%)
- Where the 60-90kgs/ha/N rates as urea were split between banded at plant and top dressed at GS31 there was no significant difference in plot grain yield. There were significant differences in grain protein with 60kgs/ha/N (10%) and 90kgs/ha/N (11.1%) when the N was applied at planting over the split treatments 60kgs/ha/N (9.6%) and 90kgs/ha/N (10.6%)
- There was no significant yield difference with the 120kgs/ha/N split treatment over the control. There may have been an error with application rates.
- There was no significant difference in plot grain yield or protein over topdress urea where GreenNV (30kgs/ha/N, 45kgs/ha/N) and EasyN (30kgs/ha/N, 45kgs/ha/N) were applied at GS31.
- No significant plot grain yield response where 60kgs/ha/N as urea banded at plant and EasyN (25kgs/ha/N) top dressed with streamers at GS60 over 25kgs/ha/N as urea. Significant protein response with EasyN (10.8%) with streamers over 25kgs/ha/N/urea (10.3%) broadcast at GS60.
- No significant plot grain yield response where 90kgs/ha/N/urea was applied at plant and 25kgs/ha/N as urea or EasyN was applied at GS60 over 120kgs/ha/N/urea applied at plant.
- No significant plot grain yield differences between PCU (5.76t/ha) with seed, PCU (5.33t/ha) banded below and to the side of the seed and Urea plus Entec (5.39t/ha) banded below and to the side of the seed at 60kgs/ha/N.
- Significant plot grain yield response where PCU at 60kgs/ha/N (5.76t/ha) was applied banded with the seed over the 60kgs/ha/N/urea (5.11t/ha) banded below and to the side of the seed. Significantly less protein with PCU (9.3%) banded with the seed over 60kgs/ha/N/urea (10%) banded below and to the side of the seed.
- Urea plus Entec (10.2%) at 60kgs/ha/N had significantly higher proteins than PCU (9.3%) with the seed and PCU (9%) banded away from the seed.

Conclusion

Significant economic gains were made from nitrogen applications at this high plot yield trial site. The highest grains were achieved by increasing yield first and then additional nitrogen moved grain protein significantly higher.

Nitrogen significantly increased grain yield up to 60kgs/ha/N and as rates increased from 90kgs/ha/N to 120kgs/ha/N protein increased using a range of different strategies, products and timings. At this site in 2013 a minimum of 60kgs/ha/N applied using various strategies, products, timing and placements was required to increase yields significantly (0.563t/ha) over the control.
Economic gains were made as an additional 30kgs/ha/N significantly increased protein from 10 to 11.1% and moved those treatments into APW. An additional 30kgs/ha/N increased protein to 11.7% and H2.

The change in grade from ASW to APW at the 90kgs/ha/N rate resulted in the best economic response to the application of nitrogen at this site. The only other treatments on this site to achieve APW grade were those where a minimum of 60kgs/ha/N was applied at planting followed by additional N.

With a significant rainfall event of 55mm 29 days after top dressing the 45kgs/ha/N applied at planting and 45kgs/ha/N top dressed produced a similar yield result to all the nitrogen (90kgs/ha/N) applied at planting but only ASW classification.

Treatments applied at GS59 of 25kg/ha/N with various products and strategies delivered a similar result. A base line level of at least 60kgs/ha of nitrogen was required to increase yield, the additional 25kgs/ha/N of nitrogen at GS59 followed by 7mm within 48hrs was sufficient to move grades from ASW to APW in 3 out of the 4 treatments.

Nitrogen use efficiency at this site using the difference method ranged from 14-52%

**Gunnedah enhanced N 2013**

![Gunnedah Enhanced N 2013](image)

*Figure 3. Spitfire sown into wheat stubble on a black Vertosol on the 10th July with reasonable soil moisture. Site management and statistical analysis by Pathway Ag with the co-operation of Andy McGovern. GSR 66mm.*

**Observations**

- Dry season, only 66mm of rain between planting and harvest
- Only statistically significant plot grain yield was where plant population was reduced due to urea in contact with seed in the seed furrow at planting
- All proteins greater than 14%. 60kgs/ha/N soil nitrogen in 0-60cm profile at planting
- All screenings 10% and above as a result of late planting and severe moisture deficit during grain fill. No crown rot symptoms observed on this site in 2013.

**Conclusions**

Dry seasonal conditions and late sowing impacted severely at this trial site in 2013
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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 message
- 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
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>Treatments</th>
<th>Garah</th>
<th>Terry Hie</th>
<th>Rowena</th>
<th>Pine Ridge</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)</td>
<td>Med (Pt)</td>
<td>Nil</td>
</tr>
</tbody>
</table>

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 gain 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.
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, EGA Gregory, Suntop and Spitfire. EGA Gregory was in the highest yielding group at four of seven sites while Dart, Suntop and Spitfire in three of seven sites (Table 3).

**Table 3. Effect of variety (averaged across N rates) on grain yield at seven sites in 2013**

<table>
<thead>
<tr>
<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</td>
<td>3.88</td>
<td>3.13</td>
<td>3.81</td>
<td>2.16</td>
<td>4.14</td>
<td>2.92</td>
</tr>
<tr>
<td>Dart</td>
<td>3.94</td>
<td>3.55</td>
<td>3.67</td>
<td>2.01</td>
<td>2.73</td>
<td>3.89</td>
</tr>
<tr>
<td>EGA Gregory</td>
<td>4.44</td>
<td>3.52</td>
<td>3.67</td>
<td>2.51</td>
<td>2.14</td>
<td>3.89</td>
</tr>
<tr>
<td>Livingston</td>
<td>4.05</td>
<td>3.39</td>
<td>3.55</td>
<td>2.25</td>
<td>2.14</td>
<td>3.89</td>
</tr>
<tr>
<td>Spitfire</td>
<td>4.32</td>
<td>3.53</td>
<td>3.47</td>
<td>2.52</td>
<td>2.80</td>
<td>3.91</td>
</tr>
<tr>
<td>Sunguard</td>
<td>4.02</td>
<td>3.47</td>
<td>3.56</td>
<td>2.55</td>
<td>2.17</td>
<td>4.04</td>
</tr>
<tr>
<td>Suntop</td>
<td>4.30</td>
<td>3.89</td>
<td>3.55</td>
<td>2.51</td>
<td>2.14</td>
<td>3.88</td>
</tr>
<tr>
<td>Sunvale</td>
<td>3.99</td>
<td>3.08</td>
<td>3.25</td>
<td>2.51</td>
<td>1.64</td>
<td>3.70</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 had consistently higher grain protein concentration across all sites – even those sites where it was the highest yielding variety. Spitfire achieved APH protein levels at six of seven sites. This contrasts with the other high yielding lines EGA Gregory, which achieved APH at one site, and Suntop 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>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>Caparoi()</td>
<td>11.9</td>
<td>11.9</td>
<td>13.4</td>
<td>13.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dart()</td>
<td>11.9</td>
<td>12.1</td>
<td>13.3</td>
<td>14.3</td>
<td>12.2</td>
<td>12.6</td>
<td>13.1</td>
</tr>
<tr>
<td>EGA Gregory()</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()</td>
<td>11.6</td>
<td>11.9</td>
<td>12.8</td>
<td>13.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spitfire()</td>
<td>12.3</td>
<td>13.2</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()</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()</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(,) and Sunvale had similar protein responses to increasing N rates and achieved higher protein levels at each N increment compared to EGA Gregory(,), Sunguard(,) and Suntop(,). EGA Gregory(,) and Suntop(,) had greater yield increases at higher N rates at this site compared to the other varieties (Figure 2). Despite protein differences between Spitfire(,) and Sunvale at the high end and EGA Gregory(,), Sunguard(,) and Suntop(,) at the low end, the rate of protein response to applied N was similar for each of these five varieties. Dart(,) responded differently to these varieties, having similar protein levels to Spitfire(,) 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](image)

At Rowena, which did not have a yield response to additional N, Spitfire(,) 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 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>Caparoi</td>
<td>83 b</td>
<td>66 d</td>
<td>89 a</td>
<td>52 cd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dart</td>
<td>83 b</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</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</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</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</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</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>

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, Spitfire and Suntop. At the lower N rates Spitfire had higher GNR compared to most other lines.
Recovery of nitrogen in soil and grain – results from 2012 trials

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 1.4g/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 50kg/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</th>
<th>Wagga Wagga</th>
<th>Coonamble</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2012 N rate (kg/ha) and timing</td>
<td>2012 N rate (kg/ha) and timing</td>
<td>2012 N rate (kg/ha) and timing</td>
</tr>
<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></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N Uptake from sowing N</td>
<td>13</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>N Uptake from Z31</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Residual N from sowing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual N from Z31</td>
<td>2</td>
<td>45</td>
<td>81</td>
</tr>
<tr>
<td>Unaccounted N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unaccounted from sowing</td>
<td>35</td>
<td>33</td>
<td>42</td>
</tr>
<tr>
<td>Unaccounted N from Z31</td>
<td>-4</td>
<td>-2</td>
<td>7</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 7.** Mineral N at four separate soil depth segments in autumn 2013 following four N application treatments at Forbes (left) and Coonamble (right) in 2012

**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.
Management impacts on N fixation of mungbeans and chickpeas

Nikki Seymour\textsuperscript{1}, RCN Rachaputi\textsuperscript{2} and Richard Daniel\textsuperscript{3}

\textsuperscript{1} DAFF, Toowoomba, \textsuperscript{2} QAAFI, Kingaroy, and \textsuperscript{3} Northern Grower Alliance

Key words
Nitrogen fixation, nodulation, rhizobia, row spacing, soil nitrate

GRDC code
DAQ00181

\begin{tabular}{|p{\textwidth}|}
\hline
\textbf{Take home messages} \\
\hline
\begin{itemize}
\item Changes to agronomy can change N fixation in grain legumes
\item In general, increasing row spacing may decrease amount of N fixed by legumes. N fixation in mungbean variety Satin \textsuperscript{2} however appears to compensate in N fixation for wider rows.
\item Varieties can differ significantly in amount of N fixation and is related to biomass.
\item High soil nitrate levels can reduce legume nodulation and N fixation by rhizobia. The addition of N fertiliser does not give any yield advantage in chickpeas or mungbeans and may reduce the amount of N available for the following crop.
\end{itemize} \\
\hline
\end{tabular}

Background

Average amounts of N fixed annually by crop and pasture legumes are around 110 kg N/ha (ranging from close to zero to more than 400kg N/ha). The actual amount fixed depends on the species of legume grown, the site and the seasonal conditions as well as agronomic management of the crop or pasture. The legume crop uses this N for its own growth and may fix significantly more than needed, leaving a positive N balance in the soil for proceeding crops.

Chickpeas were the most widely grown legume crop in Australia in 2013 with about 85 per cent being grown in NSW and Queensland. Mungbeans in the years 2008 - 2010 were up to 70000 t average production after an average of just 40000 t in 2004 -2007, mainly through improved average yields. The vast majority are grown in the northern region of Australia.

The amount of N fixed by a legume increases as legume biomass increases but is reduced by high levels of soil nitrate. In general, legume reliance on N fixation is high when soil nitrate levels are below 50 kg N/ha in the top metre of soil. Above 200 kg N/ha, nitrogen fixation is generally close to zero. The fixed N is used for the growth of the legume itself (saving fertiliser application of the legume crop) as well as potentially leaving residual N for the following cereal or oilseed crop and providing a break from cereal stubble and soil-borne diseases.

Work by Doughton \textit{et al.} (1993) clearly demonstrated the impact of increasing soil nitrate levels on N fixation of chickpeas (see Figure 1), with no yield advantage being gained by applying N. Moreover, chickpea provided a positive soil N balance when fixation rates were high and a negative balance at low fixation rates.
Figure 1. Per cent nitrogen fixed in chickpea (cv. Reselected Tyson) tops 130 days after planting for various levels of soil NO$_3$-N at crop establishment. For fitted curve, $Y = 7.05 + 88.45e^{-0.0070X}$, $R^2 = 0.95$ (from Doughton et al. 1993).

Researchers in GRDC project DAQ00181 (Optimising N fixation in grain legumes – northern region) will be working closely with the new Pulse Agronomy projects in Qld and NSW as well as some Grower Solutions projects to identify agronomic practices to optimise legume growth and N fixation without compromising crop yield.

Row spacing, plant populations and variety

Field trials with summer (mungbean) and winter pulses (chickpea) were grown in 2013 in Queensland to examine the effects of varying agronomic factors on the growth, yield and N fixation of the pulses.

Mungbean

Over the 2012/13 summer, two mungbean trials were conducted at Taabinga and Redvale, near Kingaroy, Qld. Both trials consisted of the factorial combination of the following treatments:

2 row spacings (30 and 90 cm) x 3 plant populations (20, 30 and 40 plants/m$^2$) x 3 varieties (Crystal$^\text{1}$, Satin II$^\text{2}$ and Jade-AU$^\text{3}$). Each had 3 replicates. Yields were not significantly different for any of the treatments at either trial but N fixation analyses showed that variety interacted with row spacing for the %Ndfa (per cent N in the plant shoots that is derived from the atmosphere not from soil nitrate supplies). Both Crystal and Jade-AU had much reduced N fixation as row spacing changed from 30 to 90 cm but Satin II fixed a similar high proportion of N (48 and 49%) for both row spacings (Figure 2).
Figure 2. Percent N derived from the atmosphere for 3 mungbean varieties grown at two different row spacings

**Chickpea**

Two chickpea trials were conducted in the new GRDC Qld Pulse Agronomy project in the southern region (near Dalby and Goondiwindi). Each trial had the same design including 3 row spacings (0.25, 0.5 and 1.0 m) x 3 varieties.

All 3 chickpea varieties at Dalby and Goondiwindi trials had significantly lower grain and total (grain + shoot) N uptake in kg/ha when grown at 1.0 m row spacing. Also PBA HatTrick™ was significantly lower than Boundary™ and CICA0912 in N uptake at both sites. The impact of these management practices on N fixation and hence N uptake will be examined in detail following receipt of the $^{15}$N natural abundance data and will be discussed at the Update.

**N fertiliser addition**

**Chickpea**

Trials conducted by Northern Grower Alliance in Qld and northern NSW across 6 sites in 2012 and 2 sites in 2013, showed no significant yield response in any individual chickpea trial to the addition of nitrogen fertiliser or the addition of rhizobia. In 2012, residual soil N at planting ranged from <12 to 117 kg N/ha (3 sites had 30 kg N/ha or less). Yields ranged from 1.1 to 2.0 t/ha (only one site >1.6 t/ha). The average yield response to applied N across all 6 sites is shown below in Figure 3. In this same set of trials, there was also no response to the addition of rhizobia inoculum applied as granules with the seed into the planting furrow.

In 2013, yields ranged from 0.75 to 1.3 t/ha with no response to N applied at 10 and 50 kg N/ha.

The lack of response to rhizobia inoculum overall is possibly due to adequate numbers of effective rhizobia already in the soil, however no assessments of nodulation or N fixation and residual soil N were conducted due to the lack of yield response. The seasons were hard and yields were obviously limited primarily by soil water.
Figure 3. Yield response of chickpea (variety HatTrick) to applied N (no significant differences). Values are averages for 6 trials planted across Qld and northern NSW in 2012 each with 4 replicates.

**Mungbean**

Work in Central Queensland in 2010 also indicated that nodulation was suppressed by applications of urea at rates of 10 or more kg N/ha or Triple Super at 5 or 10 kg P/ha (Figure 4). Also, no yield advantage was gained by the addition of fertiliser N (Figure 5). (Seymour et al. 2010). Pre-plant soil nitrate levels at this site started at about 80kg N/ha in the top 1m and were increased from there with applied fertilisers. There was also a history of mungbeans at this site contributing to the nodulation of the uninoculated treatments. Despite this, there was a significant yield response to inoculation.

Figure 4. Impact on nodulation of mungbean cv. Crystal from rhizobial inoculation and preplant fertiliser applications.
**Figure 5.** Response of mungbean cv. Crystal to inoculation and preplant fertiliser applications.

**Acknowledgements**

Many thanks for support from Howard Cox, Stephen Krosch, James McLean, Kerry McKenzie and NGA researchers.

**References**


**Recommended reading**

‘Inoculating legumes: A practical guide.’ Ground Cover Direct


Managing legume and fertiliser N for northern grains cropping’ Ground Cover Direct.


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Incremental P release in alkaline Vertosols

Chris Guppy, Karl Andersson and Matt Tighe (UNE)

Key words
Colwell P, BSES P, soil tests

GRDC code
GRS10029

Take home message
The sources of phosphorus (P) extracted in BSES soil tests are not all the same. Some sources release P quite quickly, whilst others may not release in the lifetime of your grandchildren.
Good root exploration (the creation of a large ‘rhizosphere’) remains critical in accessing these P sources because roots lower soil pH, which can release calcium-bound P.
Many soils may already have lost much of this extra, slow release P reserve.

Introduction
Soil testing for available P status commonly involves a Colwell test on the 0-10 cm layer. Recent GRDC funded research has highlighted the role of poorly soluble P forms in alkaline soils (the two pools at the bottom of Figure 1) in maintaining higher than expected available P values considering the amount of P removed by crops over time. It is increasingly common to measure these poorly soluble phosphates using the BSES procedure, a dilute acid extraction that dissolves calcium phosphates. These forms of P can be abundant in the alkaline Vertosols in the northern grains region (NGR), however the plant availability of the P forms dissolved in the BSES test may vary depending on soil pH buffering capacity, P mineral solubility and strength of other processes that remove P from soil solution (sorption/precipitation/immobilisation). This paper summarises some recent work that attempts to quantify the differences in availability of sparingly soluble P sources as affected by soil acidification.

Figure 1. Dominant P pools and processes in Vertisol soils.
Sparingly soluble P reserves

The poorly soluble P sources are widespread in the NGR. This was shown in partnership with David Lawrence’s group in Qld, where we analysed P forms in more than 680 sites from southern and central Queensland that were collected for paddock comparisons of soil organic matter and health. Soil P status was determined to help plan fertility strategies and pasture development.

Two thirds of the soils collected would likely respond to starter P applications based on a surface Colwell P value of less than 25 mg/kg. However, in more than half of the soils collected, Colwell P values were greater than 16 mg/kg and this coincided with these soils containing the majority of the sparingly soluble P (Table 1). As available, Colwell reserves decrease, poorly soluble P sources are increasingly used and depleted if they were originally present. In the very P deficient sites, reserves of P are insignificant. Hence, understanding how the reserves present in more than half of soils release P is important.

Table 1. Sparingly soluble P reserves of a range of Queensland soils sorted by available surface P

<table>
<thead>
<tr>
<th>Surface Colwell P (0-10) [Mean 28 mg/kg]</th>
<th>No of soils</th>
<th>Percent of soils</th>
<th>BSES-P acid (Mean) mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 4 mg/kg</td>
<td>14</td>
<td>2%</td>
<td>6</td>
</tr>
<tr>
<td>4-6 mg/kg</td>
<td>53</td>
<td>9%</td>
<td>19</td>
</tr>
<tr>
<td>7-9 mg/kg</td>
<td>71</td>
<td>12%</td>
<td>13</td>
</tr>
<tr>
<td>10-15 mg/kg</td>
<td>134</td>
<td>22%</td>
<td>29</td>
</tr>
<tr>
<td>16-25 mg/kg</td>
<td>130</td>
<td>21%</td>
<td>57</td>
</tr>
<tr>
<td>&gt;25 mg/kg</td>
<td>205</td>
<td>34%</td>
<td>325</td>
</tr>
</tbody>
</table>

P released in alkaline soils during acidification

Calcium and magnesium phosphates in soils occur as a variety of native minerals or fertiliser reaction products and these all dissolve to differing extents depending on the soil pH. These minerals dissolve so slowly that they can’t sustain yield within a crop cycle, but may be able to contribute to P nutrition within a year and partially replenish Colwell P. It is also possible that they dissolve in the root zone of plants that acidify the rhizosphere.

We selected six soils (Table 2) from the NGR to examine the solubility of P forms in soils that are broadly similar (high P Vertosols) but vary in some properties (Colwell P and pH buffering capacity). pH buffering capacity reflects the ability of a soil to resist change in pH; this is related to very high CEC or the presence of free lime in the profile. Two of the highly buffered soils had free lime.
Table 2. Selected soil properties of the Vertosols.

<table>
<thead>
<tr>
<th>Soil</th>
<th>pH</th>
<th>Colwell Ca/P ratio</th>
<th>BSES-Ca mg/kg</th>
<th>BSES-P mg/kg</th>
<th>pH buffering capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.4</td>
<td>91</td>
<td>6300</td>
<td>450</td>
<td>14        Moderate</td>
</tr>
<tr>
<td>2</td>
<td>8.3</td>
<td>44</td>
<td>12000</td>
<td>750</td>
<td>16        High</td>
</tr>
<tr>
<td>3</td>
<td>8.5</td>
<td>31</td>
<td>10000</td>
<td>380</td>
<td>27        High</td>
</tr>
<tr>
<td>4</td>
<td>9.1</td>
<td>10</td>
<td>15000</td>
<td>350</td>
<td>43        High</td>
</tr>
<tr>
<td>5</td>
<td>7.8</td>
<td>70</td>
<td>10500</td>
<td>1470</td>
<td>7         Moderate</td>
</tr>
<tr>
<td>6</td>
<td>7.8</td>
<td>75</td>
<td>21500</td>
<td>6880</td>
<td>3         Moderate</td>
</tr>
</tbody>
</table>

We incrementally acidified the soils and recovered the P with anion exchange membranes (AEM). These membranes recover P from the solution, mimicking plant uptake and minimising competitive reactions. As the soil was acidified, the pattern of P release was high to begin, as the Colwell P was extracted. In soils that don’t strongly resist change in pH, there were increases in P release around pH 7.0, 6.0 and 5.5 with large amounts of P released at higher (as well as lower) pH values. In the strongly buffered soils, considerable P release was not observed until acidification was high and pH had fallen to 6.0. The pH values at which P dissolved loosely correspond with the solubilities of known P minerals. However, what is more important is that it suggests that plant roots do not have to acidify the soil as much to mobilise P from sparingly soluble sources where the pH buffering capacity is not high. The cumulative P recovered using AEM were close to the BSES concentrations for all soils other than Soil 2 and Soil 6. Soil 6, the Fernlee soil from Central Qld, contained massive reserves of sparingly soluble P and it was unlikely that this would have been depleted over the duration of the experiment (Table 2).

Figure 2. Incremental P recovered by AEM v pH for 6 vertosols (labelled 1 – 6) with high reserves and varying Colwell values as affected by pH buffering capacity.
The reasonably complete release of P upon acidification is not unexpected. Recently published work by Dr Tim McLaren suggested that where the BSES Ca/P ratio is less than 74, the P sources they represent can replenish and supply labile pools of P in soil (Figure 3). This corresponded to BSES P values in soil that are greater than 60 mg/kg. Hence, soils with <60 mg/kg BSES P may not be able to replenish available P pools easily, and this corresponds with two thirds of those soils investigated in the Queensland study. All 6 soils in our study had lower BSES Ca/P ratios than 74 and more than 60 mg/kg of BSES P.

**Figure 3.** A regression plot for the ratio of BSES-Ca to BSES-P versus the ratio of resin to Colwell P (Published McLaren et al. SSSAJ)

The availability of these P forms to plants will be affected by the amount of acidification required to counteract the soil pH buffering capacity in the rhizosphere to dissolve Ca-P minerals. Note in Figure 4 that whilst P was released with minimal acid input in the less buffered soils, the amount of acid needed to release the P in the highly buffered soils is much higher. In practice this means that the ability of these sources to replenish Colwell pools is limited.

**Figure 4.** Cumulative P recovered by AEM versus acid added (uM/g).
Conclusion

The release of sparingly soluble P sources does vary considerably, and is affected by pH buffering capacity. Soils with free lime may release far more slowly than less buffered soils. If the sample of Queensland soils presented is indicative of wider NGR soils, it may be that 2/3 of soils have on average depleted these reserves to the point where they no longer replenish available P supplies in a timely manner. Targeted BSES investigations may identify soils that have a large supply of this slowly available P inherent in the profile.

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