What’s happened since 1996 at the Dahlen Long Term Experiment?

Robert M Norton¹, Peter Howie² and Charlie Walker³.

1 International Plant Nutrition Institute, http://anz.ipni.net Email rnorton@ipni.net
2 Melbourne School of Land and Environment, Private Bag 260, Horsham, Vic 3402.
3 Incitec Pivot Fertilizers, PO Box 54, North Geelong, Vic 3214. Email charlie.walker@incitepivot.com.au

SUMMARY

The Dahlen long term nitrogen and phosphorus experiment was established in 1996 and has been sown to a canola, wheat, barley and pulse rotation each year since then. The experiment has four rates of P (0, 9, 18, 36) applied at sowing, and 5 rates of N (0, 20, 40, 80, 160) either all at sowing or split 50:50 between sowing and the start of reproductive growth. Soil test values including P (total P, Colwell P) and N (total N, mineral N) contents have been tracked over the course of the experiment and provide information on the long term effects of fertilizer use in this region, including fertilizer nutrient use efficiency.

The initial Colwell value was 24 mg/kg (PBI 115) and after 16 crops, the soil test values were 17, 40, 72 and 125 mg/kg for the 0, 9, 18 and 36 kg P/ha/y rates. Soil mineral N values were 24, 36 and 34 kg N/ha (0-60 cm) and 58, 226 and 529 kg N/ha (0-150) for the 0, 80 and 160 kg N/ha rates respectively. Soil C values were not affected by N application and averaged 1.24 +/- 0.16, while soil C levels were 1.09, 1.25, 1.33 and 1.29 (LSD= 0.21 p=0.05) for the 0, 9, 18 and 36 kg P/ha/y rates respectively. Based on these data, P application rates that are similar to P removal will maintain the soil P test level and maintain soil C contents as well. Over application of N resulted in a large accumulation of N in the subsoil but had no effect on soil C.

Introduction

The efficient use of nutrients has at least two significant dimensions, one to enable more food to be produced with the same or lower nutrient input, and the other to reduce nutrient outflows into the environment (Smil, 2000). Current farming systems rely on nutrient inputs to maintain food production (Stewart et al. 2005) and to meet the challenge of global food security, ecological intensification is fundamental and will rely on the continued use of fertilizers to maintain productive and healthy soils (Cassman 1999).

Depending on the question asked, there are several methods to estimate nutrient use efficiency and some of these are summarised in Table 1. Agronomic Efficiency (AE) can be interpreted as a production efficiency index, giving an estimate of the marginal response in production in response to added fertilizer estimated by difference to nil fertilizer treatments. Apparent recovery efficiency (RE) is an assessment of how much nutrient is recovered in the product. Both these measures are “difference” indices (Chein et al. 2012) that rely on nil fertilizer checks so are not suited to regional assessments, and the more commonly used indices of a Partial Factor Productivity (PFP) or Partial Nutrient Balance (BNP) are derived as “balance” indices. For short term experiments, the difference methods are most appropriate, but for long term experiments – those running for multiple decades, the balance indices could be expected to approach the difference indices.

### Table 1 Dimensions of nutrient use efficiency (after Dobermann 2007).

<table>
<thead>
<tr>
<th>Term</th>
<th>Calculation</th>
<th>Range for N in cereal crops</th>
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<tbody>
<tr>
<td>Apparent Recovery Efficiency</td>
<td>RE = kg increase in uptake kg⁻¹ applied&lt;br&gt;(= (U - U_0)/F) (whole plant)&lt;br&gt;(= (Ug-U_0g)/F) (grain only)</td>
<td>0.3 to 0.5 kg/kg; 0.5 to 0.8 in well managed systems, at low N use level or at low soil N supply</td>
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<tr>
<td>Agronomic Efficiency</td>
<td>AE = kg yield increase kg⁻¹ nutrient applied&lt;br&gt;(= (Y - Y_0)/F)</td>
<td>10 to 30 kg/kg; &gt;25 in well managed systems, at low N use or at low soil N supply</td>
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<tr>
<td>Partial Nutrient Balance (Nutrient Removal Ratio)</td>
<td>PNB = kg nutrient removed kg⁻¹ applied&lt;br&gt;(= Ug/F)</td>
<td>0.1 to 0.9 kg/kg; &gt;0.5 where background supply is high and/or where nutrient losses are low</td>
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<tr>
<td>Partial Factor Productivity</td>
<td>PFP = kg yield kg⁻¹ nutrient applied&lt;br&gt;(= Y/F = (Y_0/F))</td>
<td>40-80 kg/kg; &gt;60 in well managed systems, at low N use or at low soil N supply</td>
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</table>

Y=crop yield with applied nutrients; \(Y_0\)=crop yield with no applied nutrients; \(F\)=fertilizer applied; \(U\)=plant nutrient uptake of above ground biomass at maturity; \(U_0\)=plant uptake with zero fertilizer; \(Ug\)=grain nutrient content with applied nutrients; \(U_0g\)=grain nutrient content with no applied nutrients.

This paper seeks to estimate the nutrient efficiency terms from the long-term (>15 years) fertilizer experiment at Dahlen to provide benchmarks against which current systems can be evaluated.
Methods
The Dahlen long term nutrition experiment, 10 km west of Horsham, was established in 1996 to investigate the interaction of different rates of N and P within a modern cropping system. Since establishment, the site has been in a canola, wheat, barley, pulse rotation. The soil at the site is a vertisol. The fertilizer treatments imposed are five rates of nitrogen (0, 20, 40, 80, 160 kg as urea) and four rates of phosphorus (0, 9, 18, 36 kg as triple super) applied annually over the past 17 years. No N is applied during the pulse phase of the rotation. Prior to 2011, there were two series of N treatments, either all N at sowing or split 50:50 between sowing and stem elongation.

The site has been direct drilled and stubbles retained except in 2000 when the site was burned. Grain samples were taken at harvest and yields are adjusted to 10% (cereals and pulses) or 8% moisture contents (canola). Grain N content was assessed using NIR on the whole grain in each year. Grain P content was measured for wheat and canola in 2009 and 2010, but default values for wheat (0.26%), canola (0.51%) barley (0.27%), chickpea (0.33%) and lentil (0.33%) (National Land and Water Resources Audit 2001) N and P removals were used to estimate nutrient removal (product of grain nutrient content and yield) when constructing nutrient balances for the period 1996 to 2010. Fertilizer P was applied in all years including for failed crops, but there was no N topdressed on the failed crops. No N was applied to the pulse crops, and in 2005, the natural abundance method was used to assess the amount of N derived from the atmosphere on in relation to peak biomass (Ndfa). Biomass for pulse crops was estimated as 3 times the grain yield, and Ndff as the product of the biomass by 25 kg N/ha/t (Peoples et al. 2001). P rate did not affect the rate of N fixation per unit biomass in 2005.

In 2011, the whole site (120 plots) was sampled in the top 10 cm for Colwell P, mineral N, total soil N, C and P. In addition, the 0N-0P, 0N-18P, 80N-0P, 80N-18P, 160N-0P and 160N-18P treatments were sampled for mineral N to 150 cm. Soil tests were also available from prior to the first crop in 1996. These data were analysed using a factorial analysis of variance with four rates of P and 5 rates of N combined. For this paper, data from the 0N-0P, 0N-18P, 80N-0P, 80N-18P, 160N-0P and 160N-18P treatments are presented.

Results
Table 2 shows the mean yields for each of the 14 years when crops were harvested. In all but one year, N (2005) and P (2008) treatments resulted in significant yield responses. There were interactions between N and P in over half the years, but this tended to be because of no response to N when P was not applied rather than a synergy of responses at higher rates. The timing of N application resulted in significant effects on yield in 5 of the years, but this effect was weak in the more recent years of the experiment.

<table>
<thead>
<tr>
<th>Year</th>
<th>‘96</th>
<th>‘97</th>
<th>‘98</th>
<th>‘99</th>
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<th>‘01</th>
<th>‘03</th>
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<th>‘05</th>
<th>‘07</th>
<th>‘08</th>
<th>‘09</th>
<th>‘10</th>
<th>‘11</th>
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<td>Site Mean Yield (t/ha)</td>
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</table>

Table 3 gives the soil test values for selected treatments in 1996 and again prior to sowing the 2011 crop. Mineral N levels of the lower N application rates for the topsoil are similar for the two samplings, and soil organic N and C contents have not altered significantly over those 16 years. Soil C levels significantly increased with added P at all N levels, but did not decline with added N in contrast to the report by Khan et al. (2007) from the long term “Morrow” plots in the United States of America. Gove et al. (2009) suggest that the results from the Morrow plots are confounded by the use of inappropriate controls.

Colwell P levels increased with added P but were not affected by added N, and the total P in the top 10 cm increased by approximately 0.0007% for each kg P/ha/y over the duration of the experiment (Table 3). This equates to an additional 58 kg P in the top 10 cm compared with the nil P treatments. Because P stimulated
legume growth and so the total amount of nitrogen fixed, the added P could have resulted in higher soil N and C levels, because of this increased N and C input. The soil phosphorus buffering capacity was 115 indicating a relatively low soil P demand.

Table 3. Soil N and P levels at the commencement of the experiment and before sowing 2011, for six treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N rate kg/ha</th>
<th>P rate kg/ha</th>
<th>Mineral NO₃ mg N/kg</th>
<th>Total Soil N %</th>
<th>Total Soil C %</th>
<th>Colwell P mg/kg</th>
<th>Total Soil P %</th>
<th>0-60 cm Mineral N kg/ha</th>
<th>0-150 cm Mineral N kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996 Values</td>
<td>9.6±0.7</td>
<td>0.096±0.008</td>
<td>1.14±0.18</td>
<td>24±13</td>
<td>-</td>
<td>42±3</td>
<td>83±4*</td>
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<tr>
<td>0</td>
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<td>0</td>
<td>12.5</td>
<td>0.098</td>
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<td>0</td>
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<td>72</td>
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<td>0.108</td>
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<td>17</td>
<td>0.022</td>
<td>33</td>
<td>334</td>
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<tr>
<td>80</td>
<td>18</td>
<td>18</td>
<td>25.2</td>
<td>0.133</td>
<td>1.37</td>
<td>64</td>
<td>0.028</td>
<td>40</td>
<td>110</td>
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<tr>
<td>160</td>
<td>0</td>
<td>0</td>
<td>13.0</td>
<td>0.122</td>
<td>1.10</td>
<td>19</td>
<td>0.022</td>
<td>30</td>
<td>683</td>
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<tr>
<td>160</td>
<td>18</td>
<td>18</td>
<td>20.0</td>
<td>0.127</td>
<td>1.33</td>
<td>125</td>
<td>0.033</td>
<td>40</td>
<td>348</td>
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</table>

LSD (p=0.05) 4.8 0.022 0.15 14 0.007 12 134

* 1996 value is for 0-120cm, - not recorded.

These data can be used to estimate the efficiency of various fertilizer strategies in these types of farming systems. Table 4 provides estimates of the four common nutrient use efficiencies (Dobermann 2007). Nitrogen recoveries almost tripled where P was added, and similarly, P recoveries increased greatly where N was added. Irrespective of the indicator used, the interaction of N and P is clear, with improved recoveries or higher productivity where nutrients are supplied together.

Table 4. The effect of N and P on nitrogen and phosphorus use efficiency indicators partial factor productivity (PFP), partial nutrient balance (PNB), agronomic efficiency (AE) and recovery efficiency in grain (REgr) from a long term fertilizer experiment in southeastern Australia.

<table>
<thead>
<tr>
<th>N rate kg/ha</th>
<th>P rate kg/ha</th>
<th>PFP kg/kgN</th>
<th>PNF kg/kgN</th>
<th>AE Δkg/kgN</th>
<th>REgr ΔkgN/kgN</th>
</tr>
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<tbody>
<tr>
<td>20</td>
<td>0</td>
<td>85</td>
<td>1.97</td>
<td>5</td>
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<td>80</td>
<td>0</td>
<td>22</td>
<td>0.56</td>
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<td>0.11</td>
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<tr>
<td>20</td>
<td>18</td>
<td>115</td>
<td>2.60</td>
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<tr>
<td>80</td>
<td>18</td>
<td>31</td>
<td>0.75</td>
<td>6</td>
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</table>

<table>
<thead>
<tr>
<th>N rate kg/ha</th>
<th>P rate kg/ha</th>
<th>PFP kg/kgP</th>
<th>PNF kg/kgP</th>
<th>AE Δkg/kgP</th>
<th>REgr ΔkgP/kgP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9</td>
<td>162</td>
<td>0.61</td>
<td>31</td>
<td>0.13</td>
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<tr>
<td>0</td>
<td>18</td>
<td>83</td>
<td>0.32</td>
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<tr>
<td>80</td>
<td>9</td>
<td>201</td>
<td>0.73</td>
<td>57</td>
<td>0.21</td>
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<tr>
<td>80</td>
<td>18</td>
<td>109</td>
<td>0.40</td>
<td>37</td>
<td>0.14</td>
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</tbody>
</table>

It is also important to consider the build up in soil reserves of limiting nutrients, and at this experiment, while only 14% if the applied P was recovered in crop produce (averaged across P treatments), there was a significant build up of both available and total P in the soil where P fertiliser was applied. The 18 kg P application had approximately 56 extra kg P in the topsoil (0-10 cm), and added to the mean removal of 99 kg P, this raises the recovery of P in the crop and soil to 155 kg P from a total application of 270 kg P over the duration of the experiment – 57% recovery.

These results are in general agreement with results from other long term rotations, such as Longerenong Rotation 1 – LR1. Norton et al. (2007) showed that most of the rotations at LR1 have a positive P balance and high levels of total P in the soil. The inclusion of pasture legumes or pulses into these rotations results in a positive apparent N (and C) balance in all the rotations. In general, rotations with net negative N balances show lower total soil C levels than those with legumes, and C contents tend to follow the N levels. We also undertook a simple economic analysis of the different treatments up until 2010 (before the oaten hay crop). This was based on standard costs without fertilizer from survey data (wheat $183/ha, barley $171/ha, pulse $273/ha, canola $222/ha), yields from the treatments (Table 5a), typical grain prices (wheat $220/t, barley $200/t, pulse $400/t, canola $500/t) and fertilizer prices of urea ($460/t) and TSP ($430/t). Crop failures in 2002 and 2006 were included in the calculations. Gross margins were calculated for each year and for each treatment and those are shown in Table 5b. In general, the most profitable long term strategy was 9 or 18 kg P with 20, 40 or 80 kg N.
Table 5. Average grain yields (a) and gross margins (b) for the different N and P combinations over 16 years at the Dahlen long term site.

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<thead>
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<th></th>
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<td>40</td>
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<tr>
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</table>

**Conclusion**

It is only through long-term experiments that trends in soil conditions can be tracked in response to agronomic strategies. The data reported here from a 16 year study shows that the application of N does not decrease soil C, and the application of P will increase soil N, C and P. The highest nutrient recoveries and food production efficiencies will occur when fertilizer N and P are balanced.

**Figure 1. A summary of the P status over time under different treatments.**

**References**

Lester DW, Birch CJ, Dowling CW 2009. Crop and Pasture Science 60, 218-229
Lester DW, Birch CJ, Dowling CW 2010. Crop and Pasture Science 61, 24-31