Soil test values and nutrient balances from a long term fertilizer experiment.

Robert M Norton[1], Peter Howie[2] and Charlie Walker[3].

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. www.unimelb.edu.au, Email peterwh@unimelb.edu.au
3 Incitec Pivot Fertilizers, PO Box 54, North Geelong, Vic 3214. www.incitecpivot.com.au, Email charlie.walker@incitecpivot.com.au

Abstract
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.

Key Words
Phosphorous, nitrogen, fertilizer, long-term experiments, nutrient use efficiency.

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.

This paper seeks to estimate the nutrient efficiency terms from a long-term (>15 years) fertilizer experiment and compare them to estimates from a similar experiment in the northern grains zone of Australia.

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.

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

Term	Calculation	Range for N in cereal crops
Apparent Recovery Efficiency	RE = kg increase in uptake kg^{-1} applied = $(U – U_0)/F$ (whole plant) = $(Ug-U_0g)/F$ (grain only)	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.
Agronomic Efficiency	AE = kg yield increase kg^{-1} nutrient applied = $(Y-Y_0)/F$	10 to 30 kg/kg; >25 in well managed systems, at low N use or at low soil N supply
Partial Nutrient Balance (Nutrient Removal Ratio)	PNB = kg nutrient removed kg^{-1} applied = Ug/F	0.1 to 0.9 kg/kg; >0.5 where background supply is high and/or where nutrient losses are low.
Partial Factor Productivity	PFP = kg yield kg^{-1} nutrient applied = $Y/F = (Y_0/F)$	40-80 kg/kg: >60 in well managed systems, at low N use or at low soil N supply

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.

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 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 2. Mean site yields (t/ha) and the level of significance of the yield response to N, P, fertilizer timing (T) and the interaction of N and P.

Year	1996	‘97	‘98	‘99	‘00	‘01	‘03	‘04	‘05	‘07	‘08	‘09	‘10
Crop	Barl	Cpea	Cano	Whea	Barl	Lent	Whea	Barl	Lent	Whea	Barl	Cpea	Cano
Site Mean Yield (t/ha)	3.26	1.62	1.32	1.84	3.05	0.90	3.69	1.00	1.03	2.25	1.10	0.51	2.54
N	***	***	***	***	***	***	***	***	ns	**	***	***	***
P	***	***	***	***	***	***	***	***	***	**	ns	***	***
T	***	ns	***	ns	***	ns	ns	ns	**	ns	ns	ns	*
N*P	***	ns	***	ns	***	***	***	***	ns	ns	***	ns	ns

Barl=Barley, Cpea=Chickpea; Cano=canola, Whea=wheat; Lent=lentil;
ns not significant (p>0.05); * p<0.05; ** p<0.01; *** p<0.001.

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

Treatment		Top 10 cm					Mineral N kg/ha	
N	P	Mineral NO_3 mg N/kg	Total Soil N %	Total Soil C %	Colwell P mg/kg	Total Soil P %	0-60 cm	0-150 cm
1996 Values		9.6±0.7	0.096±0.008	1.14±0.18	24±13	-	42±3	83±4*
0	0	12.5	0.098	1.08	18	0.020	24	52
0	18	15.7	0.113	1.23	72	0.032	25	64
80	0	13.2	0.108	1.10	17	0.022	33	334
80	18	25.2	0.133	1.37	64	0.028	40	110
160	0	13.0	0.122	1.10	19	0.022	30	683
160	18	20.0	0.127	1.33	125	0.033	40	348
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.

		Efficiency indicator			
N rate kg/ha	P rate kg/ha	PFP kg/kgN	PNB kgN/kgN	AE Δkg/kgN	REgr ΔkgN/kgN
20	0	85	1.97	5	0.14
80	0	22	0.56	2	0.11
20	18	115	2.60	16	0.36
80	18	31	0.75	6	0.29
N rate kg/ha	P rate kg/ha	PFP kg/kgP	PNB kgP/kgP	AE Δkg/kgP	REgr ΔkgP/kgP
0	9	162	0.61	31	0.13
0	18	83	0.32	18	0.02
80	9	201	0.73	57	0.21
80	18	109	0.40	37	0.14

Results from the Colonsay (Queensland) long term fertilizer experiment can be compared to these data from Dahlen, as the designs and data collection methods are similar (Lester et al. 2008, 2009, 2010). The REgr for N at Colonsay for the low N treatment rose from 0.44 to 0.63 kg N/kg N with applied P, and from 0.36 to 0.48 at the moderate N application rates. The northern values are higher than the southern values and this could reflect more rapid mineralization in the north due to somewhat higher soil C levels, as well as warmer conditions when the soil is moist.

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.

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.

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