Nitrogen performance indicators on southern Australian grain farms.

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Abstract
A survey was undertaken of 118 growers covering 474 fields over five years across south-eastern Australia. Crop type, grain and hay yield, residue management and fertilizer use were recorded and used to derive N partial nutrient balance (PNB) and N partial factor productivity (PFP). Estimates of the amount of N derived from biological fixation were made for pulse crops. Fertilizer N rates were higher for the higher rainfall regions, averaging 39 kg N/ha for cereals and 56 kg N/ha for oilseeds. Biological nitrogen fixation (BNF) was estimated for the fields based on legume seed or estimated pasture yields and BNF accounted for 16%, 29%, 14% and 50% of the N input for the High Rainfall Zone, Mallee, Southern New South Wales and Wimmera respectively. The regional median values for both PNB and PFP were higher than the mean values, indicating that there were relatively more high values in all regional data sets. Median PNB was less than 1 of all regions, but there were over 10% of fields in the High Rainfall Zone and the Mallee where PNB was more than 2, and the mean N deficit was highest in those regions at 13 kg N/ha/y and 10 kg N/ha/y respectively. PFP values were highest in Mallee, possibly a consequence of the inherently lower soil N status there. These data demonstrate that understanding the inherent variability in nutrient performance indictors, and also linking soil fertility assessments, is important in developing strategies to improve nutrient management.

Key Words
Partial factor productivity, Partial nutrient balance, wheat, canola, biological nitrogen fixation, fertilizer rates.

Introduction

The United Nations Environment Program has recognized the need to reconcile nutrient removal with nutrient additions, and to use these data to assess trends in nutrient performance (Norton et al. 2014). There have been reports of national N balances and their trends over the past 5 decades (Lassaletta et al. 2012, Zhang et al. 2015) and the data contributing to these reports have been derived from public databases such as FAOSTAT. These authors note that there are uncertainties about the balances due to variation in nutrient content of produce, unreliability of estimating biological N fixation (BNF) and missing some N sources (e.g. irrigation) and losses (e.g. residue burning). Furthermore there are few data on fertilizer use by region and crop, because most published reports are aggregated to a national level (e.g. Heffer 2013).

Nutrient performance may be expressing in many ways, including partial nutrient balance (PNB; nutrient removal to use ratio) and partial factor productivity (PFP; crop yield per unit of nutrient applied). While not environmental indicators, these metrics offer the benefits of being readily assessed for fields, farms, regions or nations, and together they link productivity and nutrient cycling at these scales, but take no account of changes in soil nutrient stocks.

In Australia there have been national (Angus 2001) and regional assessments (National Land and Water Resources Audit 2001) of aggregate nitrogen balances. Since that time there have been profound changes in farming systems including higher cropping intensity and increased use on N fertilizers. Edis et al. (2012) reported regional N balances using data from farm surveys, but this assessment did not include BNF, fertilizer descriptions were imprecise and the data could not be disaggregated to region and crop type. Those regional values indicated negative N balances across much of the cropping regions of Australia. More recently, Norton et al. (2015) estimated that the Australian cereal aggregate PNB was 0.82 and the PFP was 52 kg grain/kg fertilizer N.

While aggregated values are of interest, to further develop nutrient performance benchmarks as guides for farmers, data for nutrient acquisition and removal are required at the farm and field level and over multiple years to account for crop rotations. This paper reports field level data collected to develop regional nutrient performance indicators PNB and PFP and their variability, against which growers can assess their nutrient management practices to guide future strategies.

Methods

Farm records were accessed from 474 fields and 118 growers covering 34,900 ha over 4 or 5 years between 2010 and 2014 in south-eastern Australia. The data came from farms in four different agro ecological zones with different rainfall distributions and land use patterns. The zones were the High Rainfall Zone of Victoria and South Australia (HRZ), southern New South Wales (SNSW), the Victorian and South Australian Mallee, and the Victorian and South Australian Wimmera. A summary of the data collected is shown in Table 1. Thirty-seven precent of the paddocks surveyed with in wheat, while barley (21%), canola (20%), pulse crops (11%), annual pasture (6%) and fallow (2%) were the other land uses. In addition to the fields where yield and fertilizer use were reported, there were fertilizer use records collected from another 80 paddocks for shorter time periods and these data are use to report fertilizer use patterns but not nutrient performance indicators.

Table 1. Summary of survey data collected from south-eastern Australia, including approximate annual rainfall for each region and relative areas of cereals, oilseeds and legumes (pulse and pasture).

Region	Annual Rainfall (mm)	Growers	Fields	Area (ha)	% Cereal	% Oilseed	% Legume
High Rainfall Zone	>600	45	145	7,600	57	34	9
Southern New South Wales	450-600	33	63	5,300	56	34	9
Wimmera	450-350	17	82	4,200	46	14	34
Mallee	<350	23	184	17,800	70	11	16

The farm records listed the annual inputs of fertilizers. Biological nitrogen fixation (BNF) was estimated from pulse grain yield, and published values of harvest indices, the shoot N%, %N derived from the atmosphere and shoot:root ratios (Peoples et al. 2008, Herridge et al. 2009). Values used for gross BNF were between 51 kg N/ha (chickpea) to 110 kg N/ha (vetch). There were no manures applied. The BNF input from annual grazed pastures or ploughed in cover crops was based on the biomass estimated for the legumes, estimated as twice the cereal grain yield of adjacent fields.

Grain and hay yields were available in the farm records, and regional grain N values for wheat (Norton 2012) and canola (2014) were used to estimate removal in grains, and other values were derived from the National Land and Water Resources Audit (2001). It was estimated that 50% of N contained in crop residue was removed due to grazing and 80% where residues were burned.

The PNB and PFP for N were calculated from nutrient inputs and removals over a period or four or five years for each field. In calculating PNB, grain yields of all crops were included, with no adjustment for energy contents.

Results

Over the audit period, N fertilizers were applied to 94% of fields, at mean rates of 39 kg N/ha (cereals), 56 kg N/ha oilseeds and 6 kg N/ha (legumes). The application of N to legumes was because MAP was used at seeding on 54% of fields, and DAP on 8%. The most commonly used N sources were urea (44% of fields), ammonium sulfate (5% of fields) and urea/ammonium nitrate solutions (4% of fields). N use was higher in high rainfall zones and more for oilseeds (canola) than cereals (Figure 1). Figure 1 also shows the high variation in N application rates for both crops, which reflect the general strategy adopted by growers using tactical in-crop N, in response to changing seasonal conditions.

BNF accounted for 16%of the N input for the HRZ, 29% in the Mallee, 14% in SNSW and 50% in the Wimmera. These differences largely reflect the frequency of legumes in the crop rotations. In the HRZ and SNSW fewer pulse crops are suitable leading to lower BNF contributions than in the Wimmera, which has favourable conditions for the cultivation of field peas (*Pisum sativum*), lentils (*Lens culinaris*) and chickpea (*Cicer arietinum*). Faba bean (*Vicia faba*) is the dominant legume in the HRZ.

The distribution of the PNB ratio for all the fields over the audit period is presented in Figure 2a. Values presented use BNF and N fertilizers as denominator in the metric. The aggregate N balance for the whole data set had a PNB of 1.14 kg N removed per kg N supplied but the data were skewed to the right, with more higher values than lower values (Figure 2a) and this value has little meaning because there are unequal distributions among regions, as values would be reflect regions where more fields were surveyed.

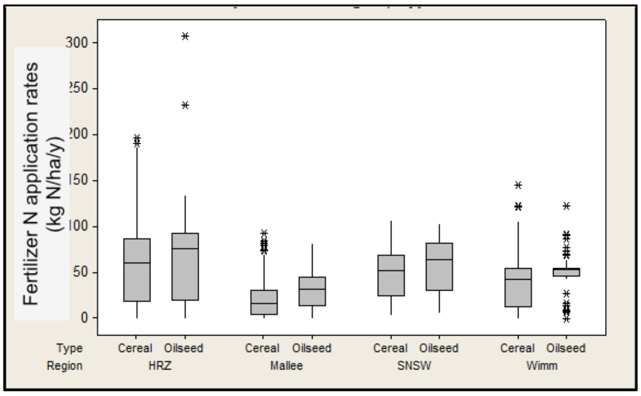

Figure 1. Mean fertilizer N rates for cereals and oilseeds in four southern Australian cropping regions over 2010 to 2014, showing the median (middle line), upper and lower quartiles (boxes), ±SE (whiskers) and outliers (asterisks).

PNB values differed among regions, with the data showing a positive skewness (Table 2) indicating relatively more larger values than smaller values in the dataset, which is not unexpected where higher values are unconstrained. The data from the Mallee showed the largest deviation between the mean and median, indicating a large number of high PNB values in that region, so that more N is removed than is supplied. Thirteen percent of fields surveyed in that region had PNB >2 but then 60% had values less than 1. There were more fields in the PNB range of 1 to 2 in the HRZ compared to the other regions surveyed.

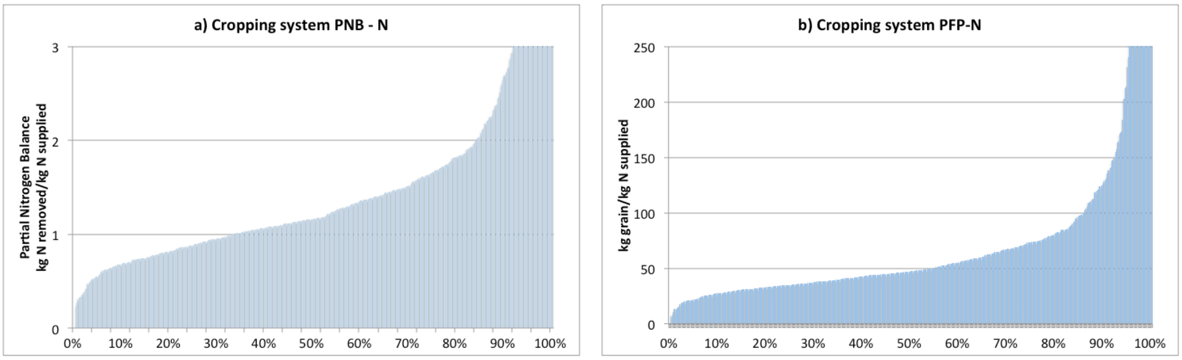

Figure 2. Cumulative distributions of nutrient performance indicators for south-eastern Australian cropping systems, a) Partial factor productivity and b) Partial nutrient balance.

Table 2. Descriptive statistics for the regional mean, standard error, median, upper and lower values and skewness for partial N balance (PNB) and partial N factor productivity (PFP) from the survey.

	Region	Mean	SEmean	Median	%<1	%>2	Skewness
PNB	HRZ	0.82	0.05	0.61	31	11	2.96
	Mallee	1.20	0.09	0.87	60	13	3.11
kg N/kg N	SNSW	0.63	0.05	0.58	41	6	1.52
	Wimmera	0.82	0.07	0.68	58	2	3.27
					%<50	%>100	
PFP	HRZ	71	6	46	61	10	4.17
	Mallee	105	10	69	34	25	3.54
kg grain/kg N	SNSW	50	4	40	70	9	2.36
	Wimmera	47	4	42	69	3	2.35

Based on these data, all regions assessed were in N deficit with more N removed than added over the audit period. Although also skewed like the PNB values, the mean N deficits (kg N removed/ha less kg N supplied/ha) for each of the regions averaged 13 kg N/ha/y in the HRZ, 10 kg N/ha/y in the Mallee, 4 kg

N/ha/y in SNSW and 2 kg N/ha/y in the Wimmera. These deficits are relatively modest but do suggest that there is likely to continue to be a small decline in soil N and organic matter with these cropping systems. This is particularly so where there are limited legume options such as in the HRZ and the Mallee.

The PFP values for the whole data set, like the PNB values are not normally distributed, with a positive skewness (Figure 2b), so the higher values result in the mean larger than the median, particularly in the HRZ and the Mallee. The "returns" on the N supplied (as expressed by the PFP) in the Mallee are higher than the other regions, which may be a consequence of the generally lower background N fertility in this region, a consequence of the low soil organic C levels. The lower N status means crops are likely to be more responsive to additional N than where native soil N is higher.

The values for PNB and PFP presented here are not meant to be definitive values for Australian farming systems, because the data set is relatively small and only derived from farmers who have good records. However, the methodology for collecting and analysing these data does provide growers with a set of nutrient performance indicators that can be viewed in combination with soil fertility indicators. It is also apparent that aggregate values such as the mean national values in Norton et al. (2015) are useful to assess gross changes, but they cloud the inherent variability that is important in developing strategies for improving nutrient performance.

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