Estimates of the apparent net mineralisation of legume N and comparisons of the subsequent recovery of legume or fertiliser nitrogen by wheat

Mark Peoples[1], Tony Swan[1], Laura Goward[1], James Hunt[1,2]

[1] CSIRO Agriculture & Food, Black Mountain Laboratories, GPO Box 1600 Canberra, ACT 2601, Australia; mark.peoples@csiro.au
[2] Current address: Department of Animal, Plant and Soil Sciences, La Trobe University, Bundoora, VIC 3086, Australia

Abstract

Results from experimentation undertaken near Junee in southern New South Wales, Australia indicated that concentrations of soil mineral (inorganic) nitrogen (N) measured just prior to sowing wheat in 2012 (0-1.6m) were 42 or 92 kg N/ha greater following lupin grown for either grain or brown manure (BM) than where the preceding crop in 2011 had been wheat or canola. The apparent net mineralisation of lupin organic N over the 2011/12 summer fallow was calculated to be equivalent to 0.11-0.18 kg N/ha per mm rainfall and 7-11 kg mineral N per tonne lupin shoot residue dry matter (DM), representing 22-32% of the total residue N estimated to be remaining at the end of the 2011 growing season. The higher concentrations of soil mineral N after the 2011 lupin treatments resulted in 55-80 kg N/ha more N being accumulated by the 2012 wheat crop (50-74% increase) compared to wheat following wheat and improved grain protein contents from ~9.8% to 12.4-13.6%. The additional N uptake was equivalent to 28% of the lupin residue N from 2011. The uptake of N by wheat grown after either the 2011 wheat or canola treatments was 25-30 kg N/ha higher (21-28% increase) when top-dressed with an additional 51 kg fertiliser-N/ha prior to stem elongation. This represented an apparent recovery of 47-59% of the fertiliser N.

Key Words

Soil mineral N; N uptake; pulses; canola; cereals; on-farm

Introduction

Elevated concentrations of soil mineral nitrogen (N) (i.e. nitrate+ammonium) are frequently observed after legume crops and pastures, but only a fraction of the legume N tends to be recovered by the next crop (Peoples *et al* 2009). It would be useful if grain-growers and their advisors had some means of predicting the N supplied by legumes to following crops when deciding how much N fertiliser to apply. The microbial-mediated decomposition and mineralisation of organic N in legume residues into plant-available inorganic forms is influenced by rainfall (to stimulate microbial activity), the amount of legume residue remaining at the end of the growing season, and the N content ("quality") of those residues. The concentrations of soil mineral N available to a following crop depends upon the total rainfall over the summer fallow period between crops, the gross mineralisation of N from both the legume residues and native soil organic N pool, and the extent of immobilisation of N by the soil microbial biomass. Unfortunately it is technically challenging to quantify gross mineralisation and immobilisation, and there is currently no easy way for farmers to estimate what effect growing a legume may have on the accumulation of soil mineral N, or how much of that N might subsequently be assimilated by a following crop. This paper reports several approaches that were applied to crop and soil data collected from an on-farm field experiment to determine (i) the apparent net mineralisation rate of N from either lupin (*Lupinus angustifolius*) stubble remaining after grain harvest, or a brown manured (BM) lupin killed with herbicide prior to grain filling (a strategy deployed by some local farmers to control herbicide-resistant weeds), and, (ii) the apparent recovery of the lupin N by a following crop of wheat (*Triticum aestivum*). The design of the study was such that it was also possible to (iii) compare the derived estimates of the apparent recovery of legume N with measures of wheat's apparent uptake of top-dressed fertiliser N when grown after a preceding wheat or canola (*Brassica napus*) crop.

Methods

The experiment was located at an on-farm field site located near Junee, NSW, Australia. Soil pH ($CaCl_2$) was 5.5 in the surface 0-10 cm. Soil mineral N prior to the commencment of the experiment in April 2011 (0-1.6m) was 100 kg N/ha. The following crop treatments were sown in a randomized complete block design in 1.8 x 20 m plots with four replicates in either late-April (lupin and canola) or mid-May (wheat):

(1).Lupin: cv Mandelup - for grain; inoculated at sowing + 75 kg kg/ha MAP (8 kg N/ha);

(2).Lupin: cv Mandelup - for BM; inoculated at sowing + 25 kg/ha MAP (3 kg N/ha), with the crop being terminated in September with 450 g/L glyphosate (Roundup CT) @ 2 L/ha + 300 g/L clopyralid (Lontrel) @ 150 ml/ha + 240 g/L carfentrazone-ethyl (Hammer) @ 25 ml/ha);

(3).Canola: cv Crusher TT– for grain; + 25 kg/ha MAP (3 kg N/ha) + 100 kg/ha urea (46 kg N/ha) and 80 kg/ha ammonium sulphate (17 kg N/ha) in-crop;
(4).Wheat: cv Lincoln – for grain; + 25 kg/ha MAP (3 kg N/ha) + 100 kg/ha urea (46 kg N/ha) in-crop.

Each plot consisted of six crop rows 305 mm apart with measurements restricted to the four middle rows of each plot. Above-ground dry matter (DM) was determined immediately prior to lupin BM termination, or 4 weeks later in the case of the grain crops at around the time of lupin mid-pod fill by removing all plants from 4×1m sections of row from each plot. Shoot DM was measured after drying subsamples at 70ºC. Grain yield was determined at maturity by mechanically harvesting the central 16 m of each plot. Dried plant and grain samples were analysed for % N and ^{15}N abundance using a 20-20 stable isotope mass spectrometer (Europa Scientific, Crewe, UK).

At the end of April 2012, plots were sampled to 1.6 m for soil N analysis, and all treatments were sown to wheat (cv Spitfire) in mid-May. The wheat sown into the 2011 lupin plots received starter fertiliser of 25 kg/ha MAP (2.5 kg N/ha), top-dressed with 100 kg/ha urea (46 kg N/ha) at stem elongation. In the case of the 2011 wheat and canola areas, each plot was split into 2x10m sub-plots with one half being treated as described above, and the other being top-dressed with 210 kg/ha urea (97 kg N/ha) just prior to stem elongation. All plants from 4×1m sections of row were hand harvested from each sub-plot prior to leaf senescence and wheat maturity. Shoot DM and N contents were measured as described above. Grain yield was determined at maturity by mechanically harvesting the central 5m of each sub-plot.

Calculations
Estimates of total plant N were derived from shoot N data by assuming ~25% total plant N for lupin, and ~30% for wheat and canola N was associated with roots (Unkovich *et al.* 2010). The last 1 m at each end of the canola and wheat plots received no fertiliser N and plants were collected from these areas at the same time as the lupin sampling and were used as "reference" plants to allow the determination of the proportion of the lupin N derived from atmospheric N_2 (%Ndfa) using the ^{15}N natural abundance technique, and these values were combined with lupin total N data to calculate inputs of fixed N:
Amount of N_2 fixed over the growing season = (total lupin N) x (%Ndfa/100)   Equation [1]
The total amounts of N remaining in crop vegetative residues and roots at the end of the 2011 growing season were calculated as:
Total residue N = (total crop N) – (grain N removed)   Equation [2]
The net effect of lupin treatments on available soil N was calculated from the differences in soil mineral N data (0-1.6m) following lupin and wheat in April 2012 and April 2013. The apparent net mineralisation of lupin N was calculated from mean treatment data assuming negligible net N release from wheat residues :
Apparent mineralisation of lupin residues (kg N/ha per mm fallow rainfall)
= [(mineral N after lupin) – (mineral N after wheat)] /(fallow rain)   Equation [3]
Apparent mineralisation of lupin residues (kg N/ha per tonne shoot residue DM)
= [(mineral N after lupin) – (mineral N after wheat)] /(lupin shoot residue DM)   Equation [4]
Where shoot residue DM = (peak biomass DM) – (grain yield)
Apparent net mineralisation of lupin N (% 2011 total residue N)
= 100x [(mineral N after lupin) – (mineral N after wheat)] /(total lupin residue N)   Equation [5]
Analysis of variance was undertaken on the DM, N and soil mineral N data to provide least significant difference (LSD) determinations. In each case P values were <0.001. However, no such statistical analyses were possible for the derived estimates of apparent mineralisation obtained using Equations [3]-[5], but as DM, N and soil mineral N provide the basis of the estimates, significant differences in these main factors were considered sufficient to confer differences in apparent mineralisation.
The apparent recoveries of legume or top-dressed fertiliser N by the 2012 wheat crop were calculated as:
 Apparent recovery of lupin N (% 2011 total residue N)
= 100x [(wheat N_{49N} after lupin) – (wheat N_{49N} after wheat)] /(total lupin residue N)   Equation [6]
Apparent recovery of fertiliser N (% additional N applied)
= 100x [(wheat N_{100N}) – (wheat N_{49N})] /(51)   Equation [7]

Results
Crop growth in 2011
The 2011 growing season rainfall (GSR: April-October) was 216 mm which was lower than the 311 mm long-term average, but heavy rainfall in February 2011 (226 mm) resulted in an annual total of 639 mm, around 130

mm wetter than the long-term average (506 mm). The soil moisture profile at the beginning of the growing season was close to full which contributed to good crop establishment, growth, and grain yields (Table 1). The lupin treatments were calculated to have accumulated a total of 290 kg N/ha (lupin BM) and 398 kg N/ha (lupin grain crop) of which 241 kg N/ha (83±3%) and 338 kg N/ha (85±4%) were estimated to have been derived from N_2 fixation, respectively. The crop harvest indices (grain as % of above-ground DM) were 35% for lupin, 43% for wheat and 30% for canola. The N content of the stubble remaining after grain harvest was higher for the lupin crop (1.4%N; C:N ratio=33) than either canola (0.7%N; C:N=60) or wheat (0.3%N; C:N=158), but was highest in the lupin BM treatment (2.6%N; C:N=15). The total amounts of N calculated to be remaining in the vegetative residues and roots of the lupin treatments at the end of the 2011 growing season were 3 to 5 times more than wheat, and ~2 to 3 times more than canola (Table 1).

Table 1. Above-ground dry matter (DM), N accumulation, grain yield and the amount of N estimated to be remaining in vegetative and root residues at the end of the growing season where wheat, canola, or lupin was grown for either grain or brown manure (BM) at Junee, NSW in 2011[a]

Crop grown in 2011	Peak biomass (t DM/ha)	Above-ground N (kg N/ha)	Total crop N[b] (kg N/ha)	Grain yield (t/ha)	Grain N harvested (kg N/ha)	N remaining in residues (kg N/ha)
Lupins BM	8.4	218	290	0	0	290
Lupins	9.9	300	398	3.5	210	188
Wheat +N[a]	11.1	106	151	4.8 (10.4% protein)	87	64
Canola +N[a]	10.6	164	207	3.2 (46% oil)	94	113
LSD (P<0.05)	1.3	36	46		11	22

[a] N fertiliser was applied to wheat @ 49 kg N/ha and canola @ 66 kg N/ha.
[b] Above-ground data adjusted to include an estimate of below-ground N (Unkovich *et al.* 2010).

Trends in available soil mineral N and estimates of N mineralisation
Soil mineral N measured in April 2012 were similar after both the 2011 wheat and canola crops (76-77 kg N/ha), but were 42 or 92 kg N/ha greater than after wheat where lupin had been grown for grain or BM, respectively (Table 2). Apparent net mineralisation over the wet 2011/12 summer fallow (515 mm Sept 2011-April 2012 after BM, or 386 mm Nov 2011-April 2012 for grain crops *cf* 214 mm long-term average) represented the equivalent of 0.11-0.18 kg N/ha per mm rainfall, 7-11 kg N per tonne residue DM, and 22-32% of the 2011 lupin residue N. These estimates represent the net effect of growing legumes for BM or grain on available soil N regardless of whether the mineral N was derived directly from mineralisation of above- and below-ground lupin residue N, arose from "spared" soil mineral N, and/or an additional release of available N from the soil organic N pool (Peoples *et al.* 2009). Although soil mineral N was not determined following grain harvest at the end of the 2011 growing season at Junee, given that lupin assimilated only 49-60 kg N/ha from the soil (calculated as: total lupin N - N fixed) while 151 kg N/ha was accumulated from the soil and fertiliser by wheat, it is likely that some of the additional available soil N measured after lupin represented unused nitrate carried over from the previous season. Nonetheless, the relationships between summer fallow rainfall, legume residue DM, or total N, and soil mineral N measured the autumn of 2012, were generally comparable to previous estimates following pasture legumes (Angus and Peoples 2012).

Table 2. Concentrations of soil mineral N (0-1.6m) measured in autumn 2012 following either wheat, canola, or lupin grown for grain or brown manure (BM) at Junee, NSW in 2011, and calculations of the apparent net mineralisation of lupin N from 2011 expressed per tonne shoot residue dry matter (DM), or as a % of total residue (above+below-ground) N.

Crop grown in 2011	Soil mineral N autumn 2012 (kg N/ha)	Apparent mineralisation of legume N (kgN/t DM)	(% residue N)
Lupins BM	169	11	32%
Lupins	119	7	22%
Wheat	77	-	-
Canola	76	-	-
LSD (P<0.05)	35		

Comparisons of wheat N uptake in 2012
Wheat sown in 2012 after either the lupin grain or BM crops accumulated 55-80 kg N/ha (50-74 %) more N than the equivalent wheat on wheat treatments (Table 3). Presumably this reflected a combination of the higher concentrations of mineral N at sowing and greater in-crop mineralisation. By way of comparison, N uptake by

wheat grown after wheat was increased by 25-30 kg N/ha (21-28%) where the supply of top-dressed fertiliser N was raised from 49 to 100 kg N/ha (Table 3). Grain proteins were higher after both lupin treatments and where additional fertiliser N was applied, but grain yields were only increased by 0.4-0.6 t/ha above that achieved by wheat grown after wheat or canola (Table 3) since the exceptionally dry spring and low GSR in 2012 (168 mm) prevented the full benefits of the increased N uptake and greater crop growth being translated into grain yield. The estimates of the apparent recoveries of legume or fertiliser N by wheat derived using equations [6] and [7] suggested that the 2012 wheat crop recovered the equivalent of 27-28% of the lupin residue N and 47-59% of the additional top-dressed fertiliser (Table 3).

Table 3. Shoot biomass, grain yield and total N uptake by wheat in 2012 following either wheat, canola and lupin grown for grain or brown manure (BM) at Junee, NSW in 2011, and calculations of the apparent recoveries by wheat of either N from lupin residues, or top-dressed fertiliser N.

Crop grown in 2011	N fertiliser applied[a] (kg N/ha)	Shoot biomass (t DM/ha)	Grain yield (t/ha)	Grain protein (%)	Wheat N Uptake[b] (kg N/ha)	Apparent N recovery (%)
Lupins BM	49	11.2	4.0	13.6	184	27
Lupins	49	10.8	3.9	12.4	159	28
Wheat	49	9.4	3.4	9.9	106	-[c]
Wheat	100	9.9	3.8	11.7	136	59
Canola	49	10.2	3.4	9.8	113	-[c]
Canola	100	10.3	3.8	11.8	137	47
LSD (P<0.05)		1.0	0.3	0.8		

[a]All 2012 wheat plots received a total of either 49 or 100 kg N/ha comprising of either 2.5 and 46 kg N/ha, or 7.5 and 92 kg N/ha applied at sowing and stem elongation (GS31); respectively.
[b] Total wheat N uptake derived from shoot N data assuming ~30% of the wheat total N was below-ground.
[c] There was no nil N fertiliser control so it was not possible to estimate N recovery for the 49 kgN/ha treatment.

Conclusions

Of the three different measures of apparent mineralisation of legume N examined here, perhaps the estimate of around 7 kg additional soil mineral N/ha per tonne legume stubble DM might be the simplest 'rules-of-thumb' for farmers and their advisors to apply. Since around one-third of the above-ground biomass is commonly harvested in grain in most pulse crops (i.e. Harvest Index = ~0.33), farmers could easily calculate residue DM as approximately twice the tonne grain harvested/ha. Consequently, ~15 x grain yield (t/ha) might be a useful guide to the expected additional mineral N prior to sowing a crop after a legume and provide a basis for modifying decisions on N fertiliser applications. The situation is likely to be more complicated for BM legume as it will be necessary to account for the impact of timing of crop termination on the accumulation of mineral N. The higher apparent recoveries of top-dressed fertiliser N by wheat compared to legume N was not surprising given the fertiliser was applied immediately prior to a peak period of crop N demand, whereas the recovery of lupin N was more representative of typical recoveries of fertiliser N applied at sowing. More experimental data for different legume species and diverse environments and soil types are currently being collated to ascertain how robust the various determinations of mineralisation and crop recovery of legume and fertiliser N may be for other dryland grain production systems of south-eastern Australia.

Acknowledgements

References

Angus JF, Peoples MB (2012) Nitrogen from Australian dryland pastures. *Crop & Pasture Science* 63, 746-758.

Peoples MB, Brockwell J, Herridge DF, Rochester IJ, Alves BJR, Urquiaga S, Boddey RM, Dakora FD, Bhattarai S, Maskey SL, Sampet C, Rerkasem B, Khan DF, Hauggaard-Nielsen H and Jensen ES (2009) The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis* 48, 1-17.

Unkovich MJ, Baldock J, Peoples MB (2010) Prospects and problems of simple linear models for estimating symbiotic N_2 fixation by crop and pasture legumes. *Plant & Soil* 329, 75-89.