Influence of a perennial ryegrass seed crop on soil nitrogen status

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Abstract

Increasing amounts of nitrogen (N) fertiliser are being used on ryegrass seed crops to ensure high yields are obtained. However, there are increasing concerns about environmental contamination due to excess nitrogen. Consequently, a field experiment was established using ^{15}N-labelled fertiliser to follow the fate of applied N. Urea-^{15}N was applied to a perennial ryegrass seed crop in April (30 kg/ha of N), August (30 kg/ha of N), September (60 kg/ha of N) and October (60 kg/ha of N). At the time of harvest, only 10% of the applied ^{15}N was removed in the seed, 29% remained in the straw, 19% in the roots and 39% in the soil organic matter. Losses of ^{15}N were minimal as the N was applied in relatively low amounts and at times when leaching was unlikely to occur. Compared with the amount of fertiliser N applied, small amounts of N were removed in harvested seed and baled straw, resulting in a net accumulation of N in the soil. The plant availability of the residual fertiliser N was very low with only 6.6% of the fertiliser remaining in the soil and stubble recovered by a subsequent wheat crop. Most of the N taken up by the wheat plants came from the soil organic N pool. Overall the high rate of N applied to the ryegrass appeared to be efficiently used by the crop with minimal impact on the environment. Nitrogen not used by the ryegrass plants contributed to the soil organic N pool.

Additional key words: *nitrogen fertiliser, nitrogen balance, nitrogen losses*

Introduction

Nitrogen (N) is needed in larger quantities by plants than any other mineral nutrient and, in most environments, is in limiting supply (Grindlay, 1997). In ryegrass seed crops, supply of N is a major determinant of seed yield (Rowarth, 1997) in the absence of moisture stress (Rolston *et al.*, 1994). In an attempt to increase yields, growers have been applying increased quantities of N-fertilisers, and rates over 250 kg/ha of N *per annum* are not uncommon (McCloy, B. pers. comm.). At the same time, there is increasing concern about environmental contamination due to increased use of N-fertilisers and Regional Councils around New Zealand are restricting the amount of N-fertiliser that can be used. In Wellington, 150 kg/ha of N can be applied each year (similar to the restriction in the Netherlands) while in Marlborough the limit is 100 kg/ha N *per annum.* Although there is discussion about whether N-fertilisers contribute directly to ground-water contamination, no research is available to quantify N-losses from ryegrass seed crops or N-availability to a subsequent crop. This research was established to investigate the fate of N applied to a ryegrass seed crop to provide information for both seed growers and the Regional Council.

Materials and methods

Field trial

The field trial was established on the AgResearch farm, Simpsons block, near Lincoln. The soil type was a Templeton silt loam (Brown soil, New Zealand Soil Classification) and the site had previously been in wheat. Three plots (12.2 m x 12 m) were drilled in March with 5 kg/ha *Lolium perenne* L. cv. Grasslands Nui. A basal fertiliser application of 150 kg/ha Cropmaster DAP (18-20-0) was applied at drilling. Nitrogen fertiliser (urea) was applied four times during the growth of the crop; 30 kg/ha of N in April, 30 kg/ha of N in August, 60 kg/ha of N in September and 60 kg/ha of N in early October. In order to follow the fate of fertiliser N, a subplot (2 m x 2 m) was marked out within each plot. Every time the fertiliser was applied, urea labelled with ^{15}N was applied to each subplot (5 atom % ^{15}N enrichment) in 4 L of water. A further 2 L of water was applied to ensure the urea was washed in and no volatilisation loss occurred (Black *et al.*, 1987).

The ryegrass seed was harvested in December. At the time of harvest, the subplots were harvested by hand. Samples for root and soil analysis (0-50 and 50-100 mm depth) were also collected. Soil, root, straw and seed samples were analysed for total N and ^{15}N on a Tracermass stable isotope analyser in conjunction with a Roboprep-CN biological sample converter. Recovery of the applied ^{15}N in the soil and herbage was calculated using the formula recommended by Hauck and Bremner (1976).

Glasshouse experiment

After harvest, fresh soil and herbage (shoot and root) samples from the ^{15}N subplots were combined together in small pots. Each pot contained 1.3 kg dry soil adjusted to a soil moisture content of 30 g/g. In order to simulate ploughing, the residues were incorporated into the middle of each pot. The N contents of the residues and soil are given in Table 1.

Pots were sown with wheat cv. Sapphire (later thinned to 4 plants per pot) and kept in the glasshouse. At maturity (three months after sowing) the wheat plants were harvested. The plant material was cut off at ground level, soil was sieved (2 mm) and the roots removed. Soil, herbage and washed roots were analysed for total N and ^{15}N as for the field trial. Exchangeable ammonium and nitrate were extracted with 2M KCl (soil: extractant ratio 1:5).

Results

Field trial

The mean ryegrass seed yield was 1800 kg/ha. Recovery of ^{15}N in seed, straw, roots and soil at harvest accounted for 97% (range 93 to 100%) indicating that very little of the applied N was lost through gaseous emission or leaching during the trial. Only a small proportion of the ^{15}N was removed in the seed (10%), most of the ^{15}N remained in the straw (29%) and roots (19%) (Table 2). Thirty nine % was recovered from the soil, mainly in organic forms as exchangeable ammonium and nitrate levels were low (data not presented).

The amount of N harvested in the seed was 38 kg/ha of N. A further 194 kg/ha of N was in the straw and roots. Using the ^{15}N data it was possible to predict that half of the plant N would have come from the fertiliser and the rest from the soil, mainly from mineralisation of organic matter.

Table 1. Concentration and content of the N in the plant residues and soil used in the glasshouse experiment.

	% N	mg N/pot	atom % ^{15}N
^{15}N-labelled soil	0.24	2520	0.45
^{15}N-labelled residues	2.8	580	0.51
^{15}N-labelled roots	1.3	260	0.69

Glasshouse experiment

At the end of the glasshouse experiment, 88% (SE=4.7) of the ^{15}N applied to the pots was recovered. Most of this ^{15}N was in the soil with only 6.6% recovered by the wheat plants (Table 3). By this time the plant residues had all decomposed resulting in an increase in soil ^{15}N enrichment from 2.1 to 2.8 mg ^{15}N per pot (data not presented). Twelve % appears to have

Table 2. Recovery of ^{15}N (as % of that applied) in soil and herbage and herbage ^{T}N uptake from fertiliser and soil at the end of the field trial.

		Herbage ^{T}N uptake (kg N/ha)		
	^{15}N recovery (%)	From fertiliser	From soil	Total
Herbage				
Seed	9.3 (±1.2)	18	20	38
Straw	29.3 (±5.5)	52	52	104
Roots	19.3 (±4.0)	34	56	90
Total		104	128	232
Soil				
0-50 mm	31 (±2.8)			
50-100 mm	8 (±0.7)			

Table 3. Amounts of ^{15}N and ^{T}N added to pots in soil, ryegrass stem and root residues, recovered by wheat plants at harvest and the proportion of herbage N accumulated as ^{15}N.

Total N added (mg ^{T}N/pot)	3360
^{15}N added (mg ^{15}N/pot)	3.81
^{T}N taken up by wheat (mg ^{T}N/pot)	63
^{T}N recovered by wheat (%)	1.9
^{15}N recovered by wheat (%)	6.6
Herbage N accounted for as ^{15}N (%)	0.4
Herbage N accumulated from native soil organic N (%)	99.6

been lost probably through gaseous emission. Only a small proportion of the N recovered by the wheat plants originated from the ^{15}N-fertiliser (0.4%), the remainder came from mineralisation of soil organic N.

Discussion

Despite the high rate of N applied to the crop, N-losses were minimal. Most of the fertiliser was applied in September/October after winter drainage had finished and so the ^{15}N was not leached. Application of N in April and March can lead to leaching losses, but the rates applied were low and the N applied was able to be taken up by the crop plants or immobilised by soil micro-organisms without loss. Volatilisation can result in a 20% loss of applied fertiliser N, depending on soil temperature (Black *et al.*, 1993), but since the ^{15}N was watered in after application, losses were minimal in this experiment. Emission of N gases via denitrification and nitrification can account for some of the fertiliser N (e.g., 14%, Tregurtha and Haynes, 1997). In this study, apparent losses via denitrification were minimal from the field experiment, although some losses occurred from the glasshouse experiment.

Of the N fertiliser applied, 59% was recovered by the ryegrass crop at harvest. This is within the high end of the 30-70% range of crop recoveries reported in the literature (e.g., Anon, 1983; Powlson *et al.*, 1986). The recovery of 39% of the ^{15}N in the soil organic matter is also within the range of 10-40% reported from other studies on the fate of fertiliser ^{15}N applied to crops (Tregurtha and Haynes, 1997).

The amount of N removed in the harvested seed was quite small (38 kg/ha of N) compared with the amount of N applied in fertiliser and taken up by the crop. If the ryegrass straw was baled and removed, another 50 kg/ha of N would have been lost. So overall there was a net gain of approximately 90 kg/ha of N. This is double the estimated net contribution of N under a short-term grass/clover sward (Williams and Wright, 1997) showing that pure ryegrass swards managed for seed production do contribute to maintaining the N-status of the soil. However, uptake of residual labelled fertiliser by the wheat plants was very small. Of the fertiliser ^{15}N remaining in the soil and incorporated into the soil in stubble, only 6.6% was recovered by the wheat plants. There have been few, if any, measurements of the residual value of the subsequent crops of fertiliser N applied to ryegrass seed crops. However, some studies have been carried out with wheat. For example, Hart *et al.*, (1993) found that 7% of the fertiliser N remaining in the soil and stubble was taken up by the subsequent crop. Other studies have also shown a similar range of recoveries between 5.3 and 15.3% (Dowdell and Crees, 1980; Myers and Paul, 1971). The proportion of residual fertiliser N taken up by the wheat crop was equivalent to only 4.5% of the original fertiliser application with the majority of the residual fertiliser N immobilised in the soil in organic forms. Since immobilisation and mineralisation occur simultaneously in the soil, it is possible that the ^{15}N cycled via both processes in the soil without being taken up by the plants. Overall, the recovery of the residual fertiliser N by the wheat plants was quite high in this experiment compared with other studies (e.g., 1.1 - 2.5%, Hart *et al.*, 1993). The high recovery is not unexpected since our trial was carried out in the glasshouse in an environment that would favour mineralisation of residues and soil organic N. Furthermore, root growth in a pot experiment is restricted to a volume of soil in which all the residues have been incorporated, thus favouring efficient recovery of mineralised N.

The results from this experiment show that N fertiliser applied to seed crops contributes to a net gain of organic N to the soil. The pool of native soil organic N in cropping soils is huge (e.g., 4000 kg/ha of N in the topsoil) and can be the main source of N recovered by the wheat plants. Maintenance of this pool is important for sustainable crop production.

Conclusions

Losses of N from applying 180 kg/ha of N to a ryegrass seed crop were minimal. Fertiliser accounted for approximately half of the crop N requirements. Overall, the amount of N applied exceeded the amount of N removed in the seed and in removed straw resulting in a net accumulation of N in the soil. This N was retained in the soil organic matter with only a small proportion becoming plant available to the subsequent crop.

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