Fate of fertiliser ^{15}N applied in early and late spring to winter wheat

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Abstract

A field experiment was carried out to compare fertiliser-N recovery in crop and soil from ^{15}N-labelled urea applied in early spring to winter wheat (*Triticum aestivum* L.) at rates of 0, 150 and 200 kg N ha^{-1}. In two additional treatments, 150 kg N ha^{-1} was applied in split applications (100 kg N ha^{-1} applied in early spring plus 50 kg N ha^{-1} at booting as either solid urea granules or dissolved in water). Grain yields and protein contents were not significantly influenced by fertiliser N applications. In comparison with 150 kg N ha^{-1} applied in early spring, split applications of N (whether in solid or liquid form) increased the recovery of ^{14}N and ^{15}N in grain at the expense of that in straw. Total recovery of ^{15}N amounted to 86-88% for the early spring-applied treatments and 99-106% for the split N applications, indicating losses of 0-14%. These were thought to be mainly gaseous losses of N_2O and N_2. Recovery of fertiliser ^{15}N in the soil ranged from 41 to 64%, and the bulk of this (63-68%) was recovered in the 0-10 cm soil layer, predominantly in organic form. The amount of fertiliser ^{15}N present in soil mineral form at harvest amounted to only 1.6 to 3.2% of that applied. Thus, a negligible amount of fertiliser N applied in spring is present in residual mineral form after harvest. Consequently fertiliser N applications at these rates are unlikely to contribute to nitrate leaching losses over the following winter.

Additional key words: *grain N, N balance, N losses, soil N*

Introduction

The major aim of farmers in applying N fertilisers is to obtain an economic response through increased crop yield and/or quality. Excessive N applications are undesirable from both economic and environmental standpoints. Environmental problems associated with the overuse of fertiliser N include pollution of surface water and groundwater with nitrate, and increased emissions of the greenhouse and ozone-depleting gas, nitrous oxide (Keeney, 1982). It is important to minimize the adverse effects of fertiliser N on the environment whilst maximising the agronomic benefits.

Wheat producers are paid by millers on the basis of both yield and quality. Among the various quality standards used grain protein content is an attribute that can be greatly influenced by fertiliser N applications. A high grain protein content requires an adequate supply of N during grain growth and development. Where the supply of N from the soil is inadequate, 'late' applications of N fertilisers at booting can significantly increase grain protein content (Drewitt, 1986; Martin, 1987; Martin *et al.*, 1989). It has been suggested that foliar applications of late N through overhead irrigation systems are more effective than soil applications (Stevenson and Daly, 1991).

The objective of this study was to determine the recovery of fertiliser N in crop and soil. The urea fertiliser was applied at 0, 100, 150 and 200 kg N ha^{-1} in early spring. Additional treatments of split applications of N (100 kg N ha^{-1} applied in early spring plus 50 kg N ha^{-1} applied at booting in either solid or liquid form) were also included. ^{15}N-labelled urea fertiliser was used to trace the fate of applied fertiliser N. At harvest, a ^{15}N balance was constructed and N losses were calculated by difference.

Materials and Methods

The experiment was carried out in 1995-96 on a Wakanui silt loam [Mottled Immature Pallic soil (Hewitt, 1993)] at the Crop & Food Research farm, Lincoln. The site had been under non-leguminous arable crops for the previous four years (oilseed rape (*Brassica napus* L.), barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.)). The soil (0-10 cm) had a total N content of 0.30%. The site was sown with winter wheat (cv. Otane) in May 1995 with a 15 cm row spacing at a seed rate designed to give 200 plants m^{-2}.

The crop was managed as a typical cereal crop for this site. It was sprayed with Glean (chlorsulfuran) at 20 g/ha, Buctril M (bromoxynil/MCPA) at 2 L/ha and Folicure (terbuconazole) at 750 ml/ha. Rainfall during the experiment was typical for the area and was supplemented by irrigation during dry periods.

Experimental treatments were 0, 100, 150 and 200 kg N ha^{-1} of urea-N applied in early spring (12 September). Two additional treatments involved split applications of 150 kg N ha^{-1}, with 100 kg N ha^{-1} applied in early spring and 50 kg N ha^{-1} applied in late spring (5 November) at booting stage either by hand broadcasting a solid pellet form (100+50S) or in a dissolved form in irrigation water (100+50L).

The experiment was arranged in a randomized block design with three replicates. In early spring, ^{15}N-labelled urea fertiliser (5.2 atom % excess) was applied to micro-plots (1.4 m x 1.2 m) in solution (dissolved in 2 L of water) using a plastic watering can. The can was rinsed with a further 2 L of water which was also applied to the plots. The liquid late N application was applied in a similar way to the early applications, with water sprinkled from above the crop canopy to simulate overhead irrigation. For the late solid N applications, urea granules were applied evenly over the plot at a rate of 50 kg N ha^{-1} in the evening. The following day, 4 L of water were applied to all the experimental plots except the 100+50L treatments.

Crop and soil samples were taken at crop maturity (30 January) from the central 1 m^2 of the micro-plot area. Above-ground biomass was divided into harvestable grain and remaining straw, dried at 70°C and weighed. A 30 cm x 20 cm x 40 cm deep sample was collected from each micro-plot for root analysis. The root material was carefully washed free, oven-dried and weighed. The soil was sampled to a depth of 40 cm (5 samples per plot) using a 25 mm diameter tube sampler and divided into the 0-10, 10-20 and 20-40 cm layers. Soil from each layer was sieved, thoroughly mixed and a sub-sample air-dried and ground (<0.5 mm).

The total N content and $^{15}N/^{14}N$ ratio of dried, ground soil and plant material were determined using a Europa Scientific Roboprep-Tracer mass spectrometer. Exchangeable NH_4^+-N and NO_3^--N were extracted from field-moist samples with 2M KCl using a 1:5 soil:extractant ratio for 2 h. Soil inorganic N (NH_4^+ and NO_3^-) was determined in filtered KCl extracts by steam distillation (Buresh *et al.*, 1982). Samples were titrated with 0.005N H_2SO_4 and then acidified to pH 3.0 with 0.1N H_2SO_4 and evaporated to dryness. The $^{15}N/^{14}N$ ratio of soil inorganic N was then determined by mass spectrometry as outlined above. Organic ^{15}N was calculated as the difference between total and inorganic ^{15}N.

Results

Grain yields and N contents were not significantly affected by fertiliser N applications (Table 1). Total recovery of ^{15}N in the plant and soil was 99 and 106% for the 100+50L and 100+50S treatments, respectively, and 86-88% for the other treatments (Fig. 1), indicating losses of 0-14% of applied fertiliser N. Mean total plant recovery (grain, straw and roots) of ^{15}N amounted to 45, 46, 43, 42 and 46% respectively for the 100, 150, 100+50L, 100+50S and 200 treatments ($LSD_{P<0.05}$ = 15.2%). Corresponding recovery of ^{15}N in the soil amounted to 41, 42, 56, 64 and 41%, respectively ($LSD_{P<0.05}$ = 24.0). Mean percentage recovery of ^{15}N in grain was 18% for the split N application and 13-15% for the other treatments (Fig. 1) ($LSD_{P<0.05}$ = 6.8). Corresponding recovery of ^{15}N in straw was 21% for split N applications and 25-29% for the other treatments ($LSD_{P<0.05}$ = 13.7). Differences in ^{15}N recovery in grain soil or straw between split applications and the other treatments were not statistically significant.

Most (63-68%) of the ^{15}N recovered in the soil was in the 0-10 cm layer (Fig. 1). The amount of fertiliser ^{15}N present in soil mineral form (NH_4^+-N and NO_3^--N) at harvest was small, with 93-96% in soil organic form. The fertiliser-derived inorganic ^{15}N in the soil at harvest amounted to 1.9, 2.7, 4.7, 4.8 and 4.0 kg N ha^{-1} for the 100, 150, 100+50L, 100+50S and 200 treatments respectively.

Discussion

The cropping history of this site (four non-leguminous crops in a row) indicated that a yield response to N fertiliser was likely. Using the net N fertility index proposed by Metherell *et al.* (1989), the site had a net index of 1 which suggests that the site could have responded to an application of 100 kg N ha^{-1}. However, despite the history of cropping, this site had a total soil N content of 0.30% which was high enough for N mineralization to supply adequate N for crop growth and development. Such a result highlights the difficulty of predicting soil N availability in cultivated soil.

Late application of N (i.e., 100+50L and 100+50S compared with 150) had little effect on grain protein content, and plant recovery of ^{14}N and ^{15}N. These

Table 1. Grain yield, grain ^{14}N content and plant ^{14}N uptake for the various experimental treatments.

Treatment (kg N ha^{-1})	Grain yield (kg ha^{-1})	Grain N (%)	Plant N uptake (kg N ha^{-1}) Grain	Straw	Roots	Total
0	6200	2.2	136	112	22	270
100	6220	2.1	130	115	24	269
150	6090	2.2	131	134	20	286
100+50L	6410	2.3	147	112	21	280
100+50S	6370	2.3	145	110	20	275
200	6340	2.2	139	140	21	300
$LSD_{P\leq0.05}$	ns	ns	ns	ns	ns	ns

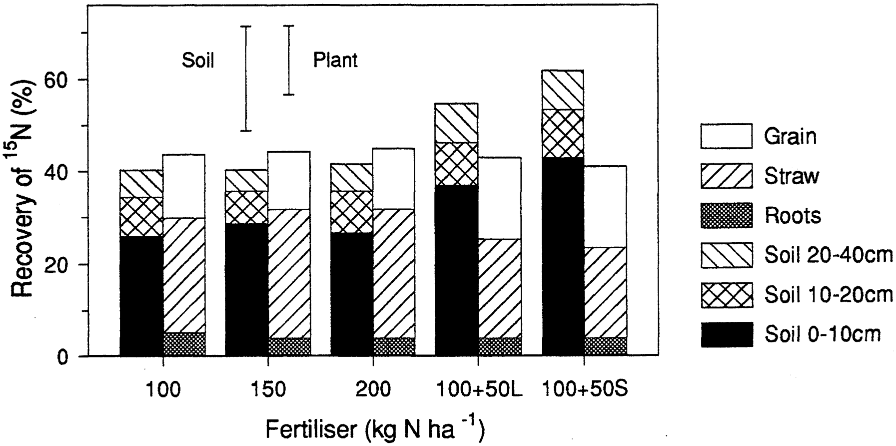

Figure 1. Percentage recovery in the soil and the wheat crop at harvest of single applications of ^{15}N-labelled urea in early spring at 100, 150 and 200 kg N ha^{-1} or split applications of 100 kg N ha^{-1} in early spring plus 50 kg N ha^{-1} applied at booting in either liquid (50L) or solid (50S) form. Vertical bars represent LSD (P<0.05) for soil (0-40 cm) and plant (grain + straw + roots).

findings contrast with those observed by other workers (Olson and Kurtz, 1982). The effects of late N tend to be most pronounced when the supply of soil N is inadequate during the period of grain growth and development. Since N supply was not limiting in this study (i.e., there was no yield response to N application) an effect of late N application was not observed.

No significant difference was observed between late N applied as urea dissolved in the irrigation water (i.e., foliar N) and as urea broadcast in solid form. Although foliar absorption of urea is known to occur readily (Goh and Haynes, 1986), most of the dissolved urea probably reached the soil surface with the irrigation water. The broadcast urea treatment was irrigated soon after fertiliser application. Thus, in both treatments, the bulk of the late N accumulated by the crop was probably rapidly absorbed from the soil by crop roots. The trend towards a higher percentage recovery of ^{15}N in the soil of the two late N treatments, compared to the other treatments, supports this theory. The late application of a significant portion of the applied N presumably allowed less opportunity for losses of N to occur prior to soil sampling at crop harvest.

Nitrogen budgets have been constructed for many different agricultural systems using ^{15}N tracer techniques (Legg and Meisinger, 1982; Goh and Haynes, 1986; Powlson *et al.*, 1986). Kundler (1970) generalized that, for arable systems, ranges of N recovery were: incorporated into soil organic matter, 10-40%; leaching loss, 5-10%; gaseous loss, 10-30%; and crop recovery, 30-70%. The crop N recovery of 42-46% measured in this study is comparable to that commonly found by other workers. Unaccounted ^{15}N, presumed to be lost, was very low compared to other studies. Since fertiliser was applied in September after the main winter leaching had concluded, leaching of fertiliser-derived ^{15}N as nitrate may have been negligible. Similarly, because the soil was irrigated immediately following urea applications, gaseous emissions of NH_3 derived from fertiliser-N would also have been minimized (Black and Sherlock, 1985). The only potential losses were, therefore, likely to have been due to gaseous emissions of N_2 and N_2O (Haynes and Sherlock, 1986).

The substantial recovery of ^{15}N in the soil (41-64%), mainly in the soil organic matter pool, is higher than that commonly reported (i.e., 10-40%), but similar values have been recorded previously (Legg and Meisinger, 1982). The comparatively high recovery of ^{15}N in the soil presumably reflects the relatively low losses of ^{15}N that occurred during the study. It is important to note that the substantial immobilization of fertiliser N into soil organic form does not necessarily mean that net immobilization of N was occurring. The amount of native soil organic N being mineralized may have been in equilibrium with the amount of fertiliser N being immobilized. Nonetheless, uptake of ^{14}N by the crop was not stimulated by fertiliser N applications. Net immobilization and mineralization may also occur in different periods of the year with the result that there is no net change in soil organic N content. For example, net immobilization of N may occur during the growing season whilst net mineralization will occur following ploughing and secondary cultivation of the land prior to sowing a following crop. The very small amounts of residual fertiliser ^{15}N measured in mineral form at harvest are in agreement with the results of European workers (MacDonald *et al.*, 1989; Powlson *et al.*, 1992). Thus, a negligible amount of the fertiliser N applied in spring is present in residual mineral form after harvest and so it contributes little to nitrate leaching losses over the following winter (Haynes, 1994). As shown by Francis *et al.* (1992, 1994) under arable farming, mineral N accumulates in the soil profile over the autumn period mainly as a result of N mineralization following cultivation of the soil. Much of this N is then leached over the winter period. Thus, since much of the spring-applied fertiliser N is immobilized into the soil organic matter fraction it may indirectly contribute to leaching losses of nitrate in the following years. That is, cultivation-induced mineralization of soil organic N will result in mineralization of some previously-immobilized fertiliser N.

Conclusion

Losses of spring-applied fertiliser N were small over the growing season ranging from 0 to 14% of that applied. Where losses occurred, they were thought to be due to emissions of N_2O and N_2 via denitrification and nitrification.

There was little spring-applied fertiliser N in mineral form at harvest and, therefore, little would be lost by leaching over the following winter. The bulk of the residual fertiliser N remained as soil organic N.

In this experiment, since N losses through greenhouse gas emissions were small and only a small amount of mineral N would have been available for leaching the following winter, the environmental impact from applying N fertiliser to wheat crops in the spring at these rates was low, at least in the short term .

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