Mineralization of cover crop N: its contribution to subsequent crop N uptake and losses

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Introduction

Recent work in the UK and throughout Europe has shown that autumn sown cover crops can substantially decrease nitrate leaching from arable land during the late autumn and winter months (Martinez et al, 1990 and Webster et al, 1992). Consequently, in order to comply with the terms of the 1991 EC Nitrate Directive (Tunney, 1992), the UK Ministry of Agriculture, Fisheries and Food recommends the use of cover crops in Nitrate Sensitive Areas (NSAs), as part of its strategy to decrease nitrate leaching from arable land.

Following incorporation into soil in spring, some of the nitrogen in the cover crop plant material will be mineralized and subject to subsequent crop uptake or loss (either by leaching or in gaseous form). The extent to which these processes occur will be determined by a number of factors, including crop management practices, soil texture, cover crop composition and the prevailing climatic conditions.

Recoveries of cover crop nitrogen by spring crops, following incorporation of cover crops, vary considerably. Thomsen (1993) reported that 29-41% of the labelled N incorporated into soil as ^{15}N labelled ryegrass was recovered by the subsequent spring barley crop, but later reported recoveries of only 8-10% (Thomsen, 1994). After incorporating ryegrass continuously for three consecutive years, Lewan (1994) reported greater leaching losses and crop yield increases of 20-25%, compared with a more conventional rotation, where no cover crop was grown. The aims of the work reported here are threefold, firstly, to compare nitrate leaching losses under cover crops with those of more conventional agricultural management practices. Secondly, to estimate the contribution cover crops make to subsequent crop N uptakes, and thirdly, to determine their effects on subsequent crop yields and nitrate leaching losses.

Materials and Methods

A field experiment designed to compare the effects of cover crops with those of other agricultural practices was established at Rothamsted in autumn 1991, on a flinty, silty clay loam overlying chalk. The experiment contained five treatments each replicated three times in a randomized block design. Forage rape and rye were chosen as cover crops on the basis of their reputation for good late autumn growth and N uptake, and winter hardiness. They were broadcast, harrowed and rolled by mid-August, following minimal cultivation of the previous spring barley crop. At the same time a weed treatment, comprising of indigenous volunteers and weeds, together with a small amount of broadcast spring barley seed, was established in the same way. This treatment was chosen for study primarily because it provides a cheaper alternative to sown cover crops and so may well be a more realistic option for the commercial farmer. One month later (mid-September) an additional six plots were ploughed, three of which were sown to winter barley, to provide a comparison with what is currently common arable farming practice. The remaining three were kept bare fallow, as a control, under which leaching losses were expected to be greatest.

In early October three ceramic cups were inserted to a depth of 90 cm in each of the fifteen plots. They were sampled periodically over the subsequent late autumn and winter to determine the effects of each treatment on the quantity of nitrate leaching through the soil. In addition, microplots (3 x 4 m) within each main plot received 18 kg N ha^{-1} as ^{15}N-labelled KNO_3. At the end of February half of the forage rape and rye plants within each ^{15}N-labelled microplot were cut, and their tops removed. The labelled tops were then transferred to areas within each main plot, from which unlabelled tops had been removed. The unlabelled tops were then returned to their corresponding labelled areas, after which all plots were ploughed in and sown to spring barley, except for those already in winter barley, which continued to maturity. Winter barley and spring barley crops received 150 and 75 kg N ha^{-1} respectively in late April, as calcium ammonium nitrate. Recoveries of labelled N in plants, residual ^{15}N in soil and overall losses of labelled N were determined in February 1992, before ploughing in. The subsequent uptakes of labelled N by both the spring and winter barley crops were determined at intervals during their growth, and at final harvest, as was that which remained in the soil. In the following autumn all plots were sown to winter barley and over-winter leaching losses were again estimated using porous cups.

Total and ^{15}N-labelled inorganic N content of soils taken in February and at final harvest were determined by steam distillation of 2M KCl soil extracts as described by Macdonald et al (1989). Crop and soil sampling, and sample processing, was done in accordance with the methods described by Powlson et al (1986). The total N and ^{15}N content of dried, ground crop and soil samples, and the ^{15}N enrichment of dried down 2M KCl distillates were determined by direct combustion analysis using a tracermass stable isotope mass spectrometer (Europa Scientific, UK). Nitrate and ammonium concentrations in soil water samples, taken using porous cups, were determined on an automated flow injection analyser (Tecator, Sweden). Total over-winter drainage was estimated to be the sum of the difference between rainfall and evaporation after the soil had reached field capacity.

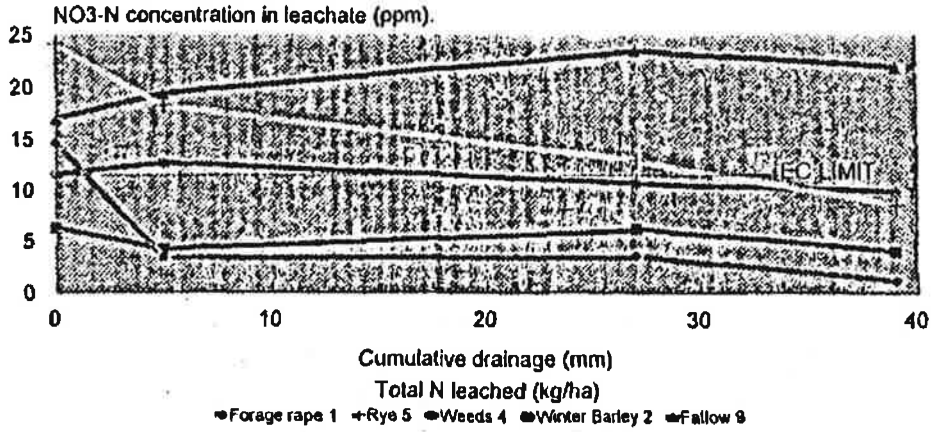
Results and Discussion

Rainfall in the autumn/winter of 1991-92 was only two-thirds the long term average and total drainage was estimated at only 39 mm. Consequently, nitrate leaching losses under all treatments were minimal (Fig. 1). However, the 9 kg N ha^{-1} leached under bare fallow was greater than the 1-5 kg N ha^{-1} leached under cover crops. Leaching losses under winter barley averaged only 2 kg N ha^{-1} and was less than that under rye and weeds. This was probably because drainage, and hence leaching, did not start until mid-December. Consequently, winter barley was well established prior to the onset of leaching and so was able to effectively decrease the quantity of nitrate in soil at risk to leaching.

In February (Fig. 2) 80 kg ha^{-1} of inorganic N (mostly nitrate) remained in the soil (0-50 cm) under bare fallow and of this about 8 kg N ha^{-1} was derived from the labelled N applied in the previous autumn. In contrast, the amount of mineral N remaining in soil under cover crops and winter barley was only half that under bare fallow, and only about 1 kg N ha^{-1} was labelled. This was largely accounted for by the 26-39 kg N ha^{-1} taken up by cover crops and winter barley, of which 6-8 kg N ha^{-1} was labelled. Forage rape contained most N and weeds took up least.

Of the labelled N applied to bare fallow plots only 56% remained in the soil (0-50

Fig 1. Effects of cover crops on NO_3 leaching measured using porous cups (1991-92)



39mm Drainage Dec18-Feb9.
Chalky loam soil.

Fig 2. Effect of cover crops on soil inorganic N content (0-50cm),in February 1992.

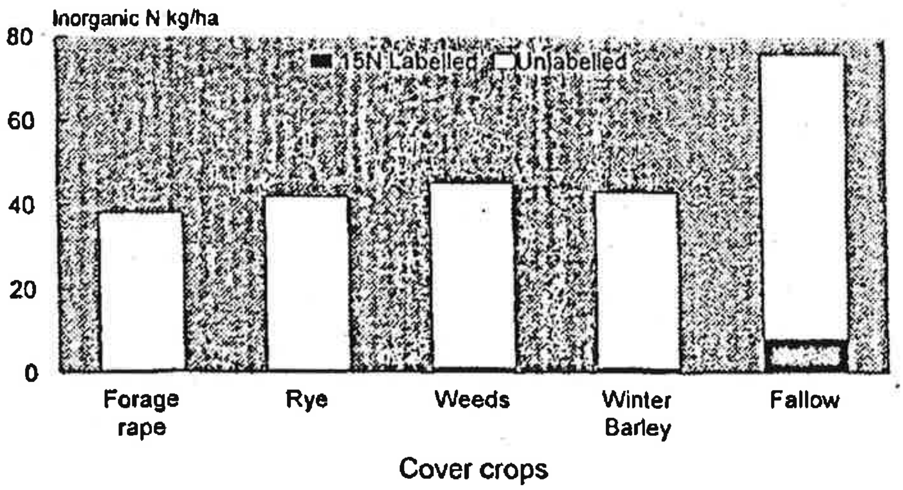


Fig 3. Cover crop 15N balances in February 1992.

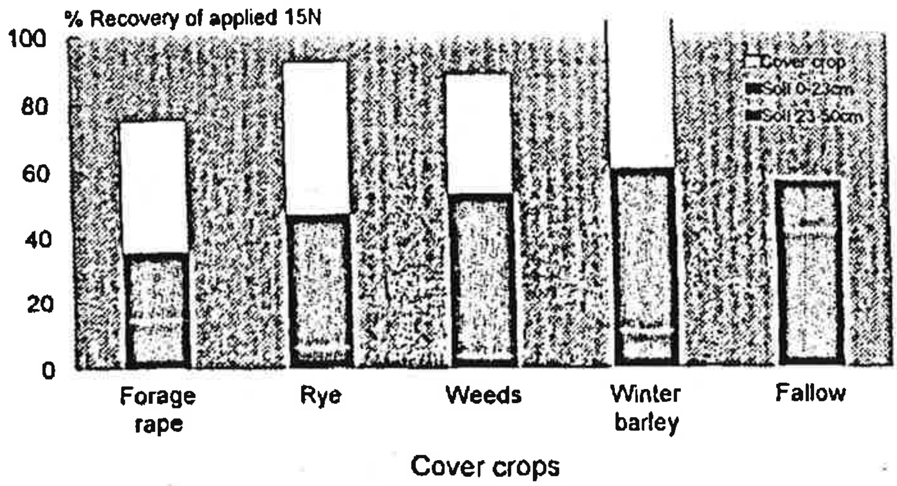
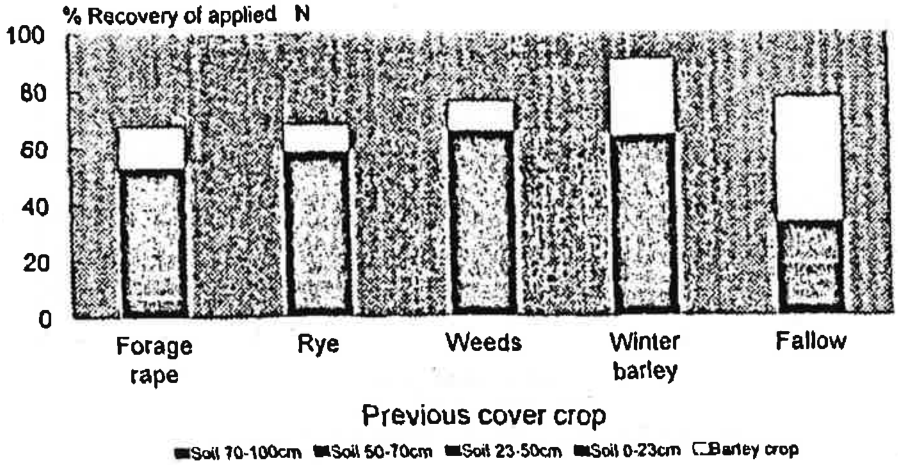


Fig 4. 15N Balances at harvest of Spring/Winter barley, following incorporation of 15N-labelled cover crops (1992).



Winter barley grown to maturity.

Fig 5. Recovery of labelled N by spring barley following incorporation of 15N-labelled cover crop tops.

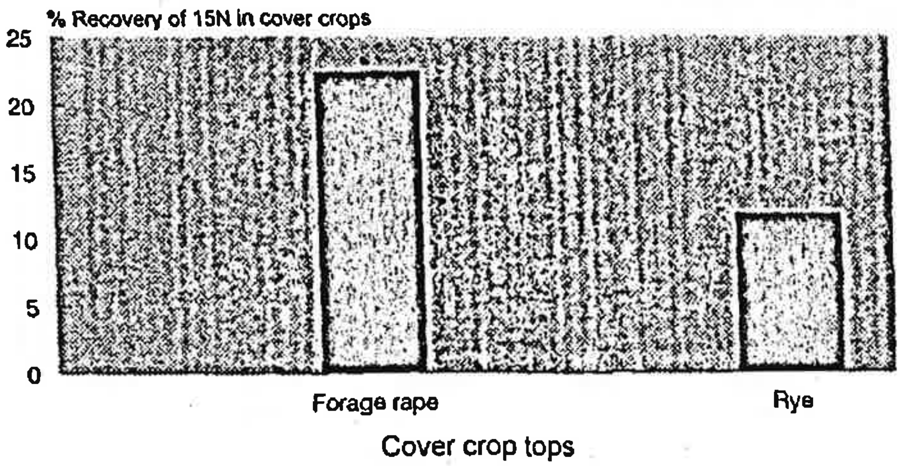
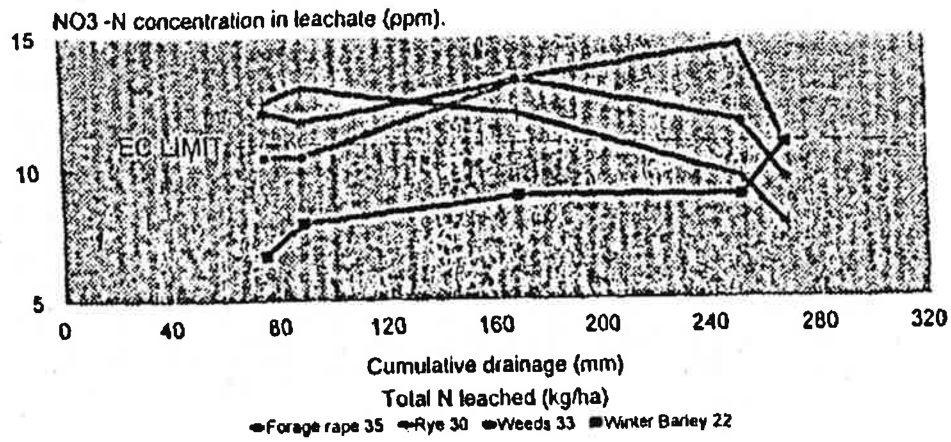


Fig 6. Residual effects of cover crops on NO3 leaching, measured using porous cups (1992-93).



268mm Drainage Sept 22-Jan 14.
Chalky loam soil.

cm) in February (Fig. 3), most of which was in inorganic forms and had leached into the sub-soil layer (23-50 cm). In contrast, 75-100% of the labelled N applied to cover crops and winter barley could be accounted for in the crop and soil at this time, with the majority of that which remained in soil being in organic forms. From these results it is apparent that in the presence of cover crops a substantial proportion of the nitrate present in soils in autumn can be immobilised in soil organic matter. This, in part, is a result of crop N uptakes and subsequent N returns to the soil in above ground plant material and roots. However, direct immobilization of mineral N by the soil microbial biomass, enhanced by carbon inputs from plant tops, roots and/or root exudates, may also play a part.

At maturity, spring barley after bare fallow contained 44% of labelled N applied in the previous autumn (Fig. 4). This was double that recovered by the winter barley crop and 3-5 times more than spring barley after cover crops. This was largely because virtually all of the residual labelled N present in the bare fallow soil in spring (Fig. 2) was in inorganic forms and so was quickly taken up by the following spring barley crop. In contrast, most of that in soil under cover crops was in organic forms and was not immediately available for crop uptake. A further possible consequence of this was that the grain yield of spring barley after bare fallow was about 1 t ha^{-1} greater than for winter barley or spring barley after cover crops. Of the labelled N applied in autumn, 68-77% was accounted for in the crop and soil (0-100 cm), at harvest of spring barley (Fig. 4) sown after cover crops and bare fallow. Of the labelled N applied to winter barley, which continued to maturity, 90% was accounted for in crop and soil at harvest. Twice as much labelled N remained in soil following cover crops and winter barley compared with that after bare fallow, and in all cases it was mostly in organic forms.

Where ^{15}N-labelled forage rape tops were cut and incorporated in previously unlabelled soils, 22% of the labelled N was recovered in the subsequent spring barley crop compared with only 12% after incorporation of rye tops (Fig. 5), indicating that the release of nitrogen from forage rape was more closely synchronized with the subsequent crop nitrogen demand, than was the case with rye. Given that cereal crop nitrogen demand is generally greatest in the early growth stages, it may be that the nitrogen in forage rape is more rapidly mineralized following incorporation into soil, than is the case with rye.

Nitrate leaching losses under winter barley, sown following incorporation of cover crops were estimated at 30-35 kg N ha^{-1} (Fig. 6), and were slightly greater than the 22 kg N ha^{-1} leached after winter barley. A similar trend was seen in a subsequent experiment on the same site (1993-94), when leaching losses following incorporation of cover crops were 26-32 kg N ha^{-1}, compared with only 17-21 kg N ha^{-1} after winter barley and bare fallow, indicating that the mineralization of N incorporated in cover crops may contribute to subsequent nitrate losses from arable soils.

Conclusions

In the autumn/winter of 1991-92 early sown forage rape, rye and weeds effectively decreased nitrate leaching from arable land compared with that under bare fallow. However, because of the relatively dry conditions they were no more effective than the later sown winter barley crop. In addition, winter barley, grown to maturity, was more effective at decreasing losses of ^{15}N-labelled nitrate, applied in autumn, than were cover crops. Because nitrate leaching was minimal the establishment of cover crops decreased the quantity of mineral N in soil available for subsequent crop growth in spring. This may have resulted in the yield penalty observed in the following spring barley crop.

The mineralization of labelled N, following incorporation of ^{15}N-labelled forage rape was more closely synchronized with subsequent crop nitrogen demand than was the case with rye, indicating that the mineralization of N incorporated in forage rape may well have been more rapid than with rye.

The greater nitrate leaching losses measured in the winter following incorporation of cover crops, compared with those after winter barley and bare fallow, indicate that, whilst they may be effective at minimising nitrate leaching losses during the period of their growth, they may contribute to increased leaching losses following incorporation.

Acknowledgements

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