The Fate of Nitrogen from Crop Residues of Broccoli, Leek and Sugar Beet

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Abstract

Environmental concern has lead to legislation on fertilization to reduce nutrient losses to the environment. Reducing N input may be inadequate for crops that have a high N content in their residues. Reducing N input will negatively affect yield, but the residues remain. Management of crop residues may then be a more effective strategy to reduce N losses, notably nitrate leaching. Two experiments were carried out in 2006-07 and 2007-08 to study all emission routes of N from crop residues of broccoli, leek and sugar beet, and to determine the contribution of N from the residues to nitrate in groundwater. Crop residues were surface applied or rototilled, and compared with a blank and application of fertilizer N. About 11 to 16% of the N-content was lost to the air. Total N-losses to the air as ammonia and through denitrification were little affected by tillage, but partitioning was. When residues were left on the soil surface, most N was lost as ammonia, when the residues were rototilled, most N was lost through denitrification. Year strongly affected N leaching from crop residues, and the fraction of N from crop residues that was leached was twice as high in 2006-07 than in 2007-08. Tillage increased N leaching from broccoli, but had little effect with leek or sugar beet. Between 20 and 60% of the N content of residues of leek and broccoli was leached. Removal of residues after harvest will therefore contribute to reduce N leaching. However, options for treatment and re-use of the residues need to be studied as well as the effects on nitrate leaching and gaseous losses to assess the effects of the system as a whole.

INTRODUCTION

To protect groundwater and reduce or prevent eutrophication of surface waters, the EU has adopted the Nitrates Directive and the Water Framework Directive. These directives are implemented in the Netherlands Action Programme that defines crop-specific limits to N inputs. These crop-specific N standards were based on current N recommendations. The high nitrate concentrations on sandy soils, especially on deeper groundwater tables, indicate that further action is required. N standards can be cut to levels below the N recommendations, especially for crops that have a high N surplus. However, some crops (e.g., broccoli) have a high N surplus because of a high N content of the crop residues. Cutting back N standards may then have little effect on N leaching but negatively affect crop yield. Instead, management of crop residues may be a more effective strategy to reduce nitrate emissions to groundwater and surface waters.

Little is known about what part of the N content of crop residues is lost to groundwater. To predict effects on N leaching of different options of management of crop residues, knowledge of the fate of N from crop residues is required. The objective of this study was to monitor all emission routes of N from crop residues, and to determine the contribution of N from crop residues to nitrate in groundwater.

MATERIALS AND METHODS

Field experiments were carried out in 2006/07 and 2007/08 on a sandy soil with crop residues of broccoli and leek. Experiments in 2007/08 included residues from sugar beet, broccoli and leek. Residues of broccoli and sugar beet were collected from farmers' fields; residues of leek were derived after harvest and cleaning on the farm. About 100-150 kg N ha^{-1} in crop residues was applied on the surface of 20 × 20 m plots in early November. Prior to the experiment, potatoes (2006) or maize (2007) was grown. Plots with residues were either rototilled or left undisturbed. A blank was included, as well as a treatment where only fertilizer (150 kg NO_3-N ha^{-1} as calcium nitrate) was applied in absence of residues. Both blank and the fertilizer treatment were undisturbed.

Breakdown of crop residues was studied using nylon litter bags of 50 × 50 cm that were either placed on the soil surface or covered by 10 cm of soil. Soil mineral N (SMN) in the soil profile was studied by soil sampling at depths of 0-30 cm, 30-60 cm and 60-90 cm. Nitrate concentration in the soil solution was studied by extracting soil moisture at depths of 30, 60, 90, 120, 150, 180 and 210 cm using macro-rhizons (Rhizosphere Research Products, Wageningen, the Netherlands). Nitrate concentration in the solution was determined using test strips and a reflectometer (Rqeasy; Merck, Darmstadt, Germany). Microbial biomass N was determined in soil samples (0-30 cm) by fumigation extraction (Brookes et al., 1985). Actual denitrification was studied in core samples from the field (0-20 cm), taken carefully from positions with representative amounts of residues. The samples were further analyzed in the lab using the acetylene inhibition method (Van Beek et al., 2004). Samples of litter bags and for determination of SMN, N in microbial biomass and denitrification were taken on a monthly basis. Soil moisture was extracted twice a month (to determine its nitrate content). Ammonia emission was studied in a separate experiment using volatilization chambers (Le Cadre et al., 2005). All ammonia emitted from the residues was collected in an acid trap.

Measurements of breakdown of crop residues (litter bags), ammonia emission and denitrification were done until the middle of March. SMN, soil moisture and microbial biomass were measured until the end of June. By the middle of March spring barley was sown and N-uptake of the crop was determined in early July.

Leaching of N from crop residues to groundwater was examined in three different ways:

1. Comparison of the increase in nitrate concentration in groundwater relative to that of the fertilizer treatment with a known amount of leachable N,
2. Calculation of N fluxes from the measurements of nitrate in soil moisture and data on rainfall and evaporation,
3. By subtracting estimates of gaseous losses, amounts of N remaining in the residues (litter bags) and in the soil profile (SMN), and amounts in soil microbial biomass from the total N input.

RESULTS AND DISCUSSION

The weather differed between both experimental seasons (Fig. 1). In 2007-08, the temperature in November and December was about 2.5 degrees lower and the total precipitation from November until March was about two thirds of that of 2006-07.

Ammonia emission only occurred when the crops were left on the soil surface and was negligible after rototillage. Averaged over both experiments, cumulative emission of ammonia was between 8 and 10% of the N-content of the residues. In 2006-07 ammonia emitted earlier than in 2007-08.

N-losses through denitrification were also affected by tillage. From broccoli and sugar beet, an average of 2% of the N-content of the residues was lost when they were left on the soil surface. After rototillage, almost 10% of the N-content was lost. Denitrification from residues of leek was about 5% higher than of broccoli and sugar beet.

SMN was increased by application of crop residues (Fig. 2). In 2006-07 SMN increased earlier than in 2007-08. After the middle of January SMN strongly decreased in 2006-07, whereas in 2007-08 SMN remained relatively constant until the middle of March. SMN was higher when the residues were rototilled, indicating an increased breakdown of residues compared to no tillage. Some of the SMN however may have resulted from increased mineralization after tillage.

Measurements of SMN and results of the macro-rhizons showed that by early

March almost all N from the fertilizer was leached into the groundwater at 1.5 m depth (data not shown). The three different approaches to quantify the contribution of N from crop residues to nitrate in groundwater gave different results. Details of these analyses can not yet be given. Preliminary results as average of the three approaches are shown in Table 1. A higher percentage of N from crop residues was leached in 2006-07 than in 2007-08. This is attributed to the higher temperatures and faster breakdown of the residues in 2006-07, combined with the higher amount of precipitation that leached most mineral N out of the top layers. Year therefore has a large impact on the fraction of N from residues that is leached over winter. In our experiments the difference was about a factor 2. Nevertheless, removal of crop residues can substantially contribute to reduce N leaching: the amount of N leached from broccoli varied between 24 and 82 kg ha^{-1}, and from leek between 31 and 50 kg ha^{-1}. Leaching of N from sugar beet was low. Sugar beet was only tested in the second year, when losses were lower than the first year. Low leaching losses from sugar beet have been found before (Olsson and Bramstorp, 1994) and may be specific to this crop.

N leaching from crop residues can be reduced by removing them from the field, especially easy degradable crop residues with a high N content. After removal from the fields, the crop residues need to be used or treated elsewhere. Options are composting, co-digestion or use as fodder. Emissions that occur with these alternative routes - including with the application of their end products such as digestate or compost - should be studied to assess overall effects on N losses. Management options when the residues remain on the field are tillage and timing of application. No tillage may delay breakdown of residues (Lachnicht et al., 2004) and thus reduce N leaching. In broccoli, no tillage reduced N leaching by 15 to 20% of the N content. For leek, no such reduction was found. Timing of application to retard breakdown is difficult to change as this is generally linked to harvest time.

CONCLUSIONS

Total N-losses to the air were little affected by tillage, but partitioning was. When residues are left on the soil surface, most N is lost as ammonia, when the residues are rototilled, most N is lost through denitrification.

Year strongly affected N leaching from crop residues, and the fraction of N from crop residues that was leached was twice as high in 2006-07 than in 2007-08. Tillage increased N leaching from broccoli, but had little effect with leek or sugar beet.

Between 20 and 60% of the N content of residues of leek and broccoli was leached. Removal of residues after harvest therefore contributes substantially to reduction of N leaching. However, options for treatment and re-use of the residues need to be studied, along with effects on nitrate leaching and gaseous losses to assess overall effects on N losses.

ACKNOWLEDGEMENTS

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Tables

Table 1. N leached below 90 cm early March (percentage of N applied).

Treatment		N applied (kg ha^{-1})		N leached (%)	
		2006-07	2007-08	2006-07	2007-08
Fertilizer		150	150	100	100
Broccoli	Top	136	118	40	20
	Rototilled	136	118	60	35
Leek	Top	110	155	45	20
	Rototilled	110	155	35	20
Sugar beet	Top	-	72		5
	Rototilled	-	72		10

Figures

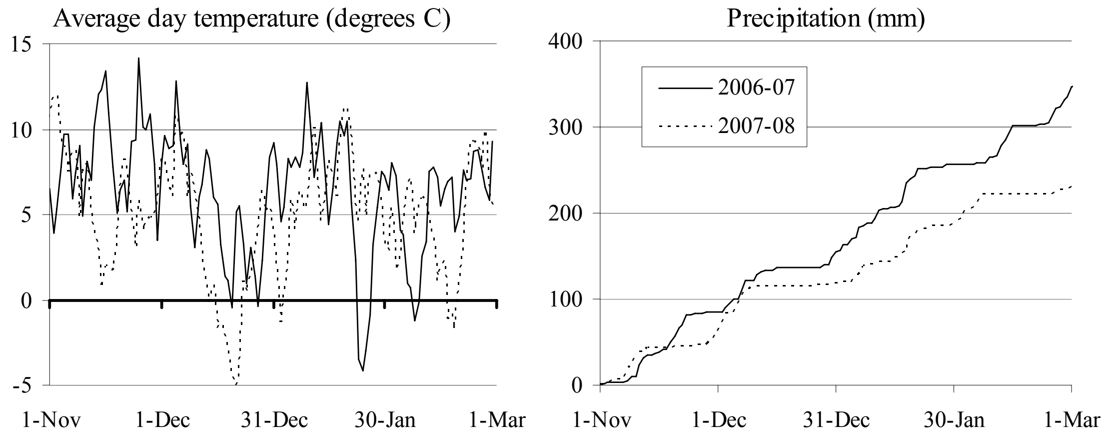

Fig. 1. Average day temperature (left) and cumulative precipitation (right) during the winters of 2006-07 and 2007-08.

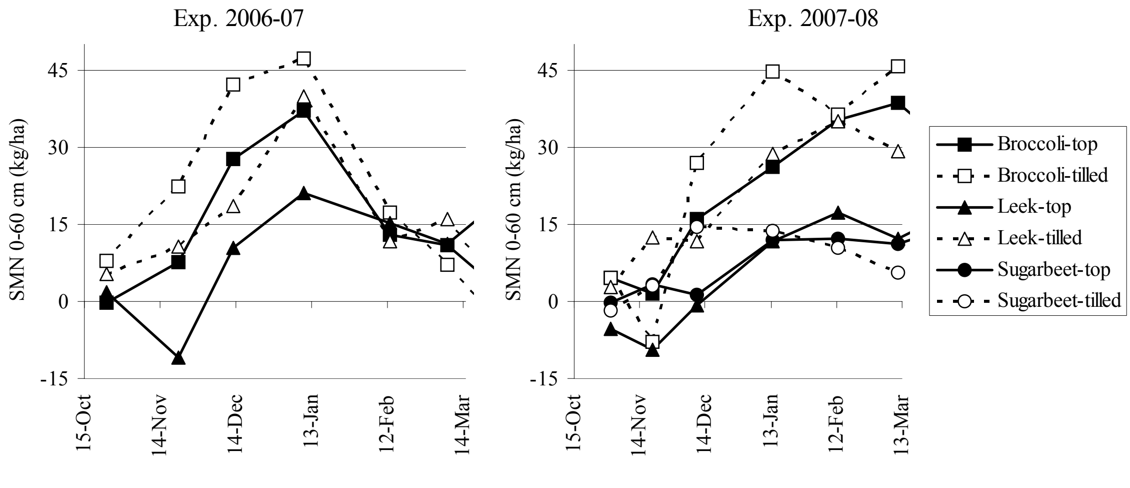

Fig. 2. Increase of soil mineral N (kg ha^{-1}) after application of crop residues during the winters of 2006-07 and 2007-08.