Simulation of nitrate loss by denitrification and leaching from grassland under cutting

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Abstract

High nitrogen (N) fertilisation rates are applied to grassland of dairy farms in the Netherlands, which causes high N emissions to the environment. Effective ways of controlling these emissions were investigated with a detailed simulation model for grassland management, water and soil C and N dynamics. Various N fertilisation strategies have been explored for a specific sandy soil in the Netherlands, including the effects of irrigation on nitrate leaching, grass yields and denitrification. Lowering the mineral N fertilisation in the non-irrigated situation was effective: grass dry matter yield was reduced by 5% only, whereas the nitrate concentration dropped by 43% which was needed to realise the target of 50 mg nitrate l^{-1} on average. Irrigation in this study also had a large decreasing effect on nitrate leaching and can be very helpful in controlling nitrate leaching on intensively used grasslands that (occasionally) suffer from drought conditions. Denitrification was responsible for most (> 70%) of the nitrate loss by denitrification and leaching together. Denitrification was strongly reduced when mineral N fertilisation was lowered, but increased if irrigation was applied. N_2O emission from the soil surface was positively related to mineral N fertilisation and it was concluded that the selected measures for controlling nitrate leaching in this study are also very effective in decreasing N_2O emission from sandy soils.

Keywords: denitrification, grassland, leaching, modelling, N_2O, nitrogen, yield,

Background and objectives

Most of the grassland on dairy farms in the Netherlands is used intensively, for which high N fertilisation rates are needed. Besides high grass yields, this causes high emissions of N to the environment (atmosphere, surface water and ground water). Related problems due to these high emissions are e.g. the eutrophication of natural waters, increased greenhouse gas effects and a poor drinking water quality. Society is concerned about these effects and seeks effective ways to control the emissions. Lowering the N input level is one of the strategies to reduce emissions to acceptable levels. A simulation study for a specific soil type has been conducted to answer the following questions:

1) how to fertilise grassland in order to limit the N concentration at a specified depth to 50 mg nitrate l^{-1},
2) what are the consequences of less N fertiliser for grass yields and
3) what is the effect on denitrification and the N_2O emission to the atmosphere?

Material and methods

Detailed dynamic models for grassland management, water and soil C and N dynamics (*CNGRAS*, see Conijn, 2005 and *FUSSIM2*, see Heinen and De Willigen, 2001) have been coupled to explore various fertilisation strategies and their effects on grass yield, nitrate leaching and N_2O emission. For the simulation study a sandy soil has been selected with an organic matter content of 4.1% in the top soil (0-20 cm). The soil can be characterised as moderately moist with mean highest and lowest groundwater level of -10 cm (winter) and -125 cm (summer), respectively. Only vertical movement of water and solutes through the soil has been simulated in this study. The grass sward (100% *Lolium perenne* L.) was cut approx. 5 times per year (no grazing). Total N fertilisation consisted of a basic application of slurry (total N of 245 kg ha^{-1} y^{-1}) and a variable amount of mineral fertiliser (0 – 220 kg N ha^{-1} y^{-1}), split into 3-5 applications per year. Two choices were made with respect to irrigation: zero irrigation and optimal irrigation to prevent growth reduction due to drought stress. Other input parameters apply to average farm conditions in the Netherlands (Conijn and Henstra, 2003). Calculations were performed for a period of one year using 15 separate years with different weather conditions to determine mean yearly values. Calculated N leaching and nitrate concentration apply to the net fluxes of water and N across the soil boundary at 100 cm depth. Denitrification is given as total N loss via N_2 and N_2O from the whole soil profile (0–350 cm) and N_2O emission refers to the net emission from the soil surface into the atmosphere.

Results and discussion

Results of this simulation study have been compared with data from a number of experiments. Figure 1 shows the comparison with an experiment from a similar site, but with slightly different management and soil/weather conditions. The dotted line has been derived from the data of the experiment, averaged over a period of five years (Van der Meer, 2000), and the data points represent the average results of the non-irrigated model calculations for 15 years. All data points lie close to the experimental line, which gives confidence in the model ourcome.

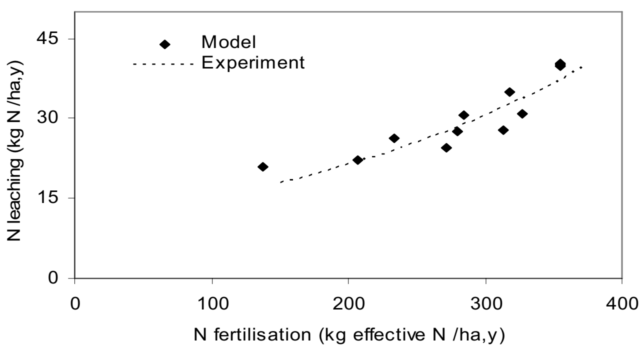

Figure 1. *N leaching as function of N fertilisation. Results of this study (markers: 'Model') are plotted together with results of an experiment conducted in 1980-1984 (dotted line: 'Experiment').*

Table 1 contains a summary of the calculated results on agronomic and environmental key data of cut grassland of this sandy soil in the Netherlands (more results can be found in Conijn and Henstra, 2003). In the non-irrigated situation and with the recommended N fertilisation level ('economic optimum'), the average nitrate concentration in the percolation water at 100 cm soil depth exceeded the target of 50 mg nitrate l^{-1} by 74%. By lowering the mineral N fertilisation by circa 110 kg N ha^{-1} y^{-1}, the target could be realised, at least on average. Total N loss (via denitrification and leaching) then dropped from 132 to 85 kg N ha^{-1} y^{-1} and the N_2O emission was reduced by 40%. Calculated reductions of grass yields were relatively small (-5% for dry matter and -11% for nitrogen), which is consistent with the results of Aarts *et al.* (2005). In the irrigated option irrigation was only needed in 10 out of 15 years with a mean application of 57 mm y^{-1}. Irrigation was very effective in reducing nitrate leaching: the nitrate concentration exceeded the target by only 11% if the recommended fertilisation was combined with optimal irrigation. To bring the nitrate concentration further down to 50 mg l^{-1}, the N fertilisation should be reduced by 57 kg ha^{-1} y^{-1} (approximately half of the reduction that was necessary in the non-irrigated situation). In this situation the loss of N by denitrification was enhanced (+ 21 kg N ha^{-1} y^{-1} compared to the non-irrigated situation), partly because of the irrigation itself but mostly due to the higher (allowed) N input level. In the irrigated situation the N_2O emission dropped by 18% (cf. 40% in the non-irrigated situation).

Table 1. Calculated grass yields and nitrogen dynamics in cut grassland on a specific sandy soil in the Netherlands. Each value represents the mean of 15 individual model runs using the years from the period 1971-1985.

	Non-irrigated		Irrigated	
	A	B	A	B
N-fertilisation (kg effective N ha^{-1} y^{-1})	355	242	355	298
Dry matter yield (kg ha^{-1} y^{-1})	10900	10400	12000	11600
Nitrogen yield (kg ha^{-1} y^{-1})	353	316	377	351
Denitrification (kg N ha^{-1} y^{-1})	92	61	100	82
Leaching (kg N ha^{-1} y^{-1})	40	24	27	25
Nitrate (mg l^{-1})	87	*50*	56	*50*
N_2O emission (kg N ha^{-1} y^{-1})	6.5	3.8	5.0	4.1

A: Fertilisation level, recommended to farmers as economic optimum in the non-irrigated situation.
B: Fertilisation level, corresponding to a mean of 50 mg nitrate l^{-1} in the percolation water at -100 cm.

Conclusions

From this study can be concluded that for this specific sandy soil in the Netherlands a reduction in mineral N fertilisation is an effective way to bring down the nitrate concentration to 50 mg l^{-1} because the large relative change in N loss is accompanied by much smaller relative changes in grass yields. It can also be concluded that irrigation is a very helpful measure to control nitrate concentration in percolation water which illustrates the importance of an adequate water supply in relation to N leaching on intensively used grasslands.
Denitrification was responsible for a large part of the calculated total loss of N by denitrification and leaching from the selected sandy soil: only 29% (non-irrigated) or 22% (irrigated) of the total loss was leached below 100 cm soil depth, whereas the remainder (> 70%) had been denitrified mainly into N_2 and N_2O. Measures that were taken to reduce the nitrate concentration also caused a decrease in N_2O emission. If a decrease of e.g. 6% in N_2O emission is pursued (cf. Kyoto climate conference in 1997), no additional measures were needed in this study after realisation of the water quality target of 50 mg l^{-1}.

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