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Relation between N input and nitrate concentration of groundwater on arable farms [1)]

Het verband tussen de N-toevoer en de nitraatconcentratie van het grondwater op akkerbouwbedrijven

SUMMARY

A statistically significant relation was found between the NO_3^--N concentration of the shallow groundwater under intensively farmed arable fields and the surplus of N (N supply minus N removal via crops), groundwater level and soil type. The average NO_3^--N concentration was 9 mg/l in the water samples from the arable farm that used only inorganic fertilizers, but 30 mg/l in the samples from farms that used inorganic fertilizers as well as animal manures. Measures to decrease the surplus of N and to reduce the NO_3^--N concentrations in groundwater and drainage water are proposed.

SAMENVATTING

Er bestond een significant verband tussen de NO_3^--N concentratie van het bovenste grondwater onder akkerbouwpercelen en het surplus aan N (N-aanvoer minus N-afvoer via oogstprodukten), grondwaterstand en grondsoort. Op het akkerbouwbedrijf dat alleen minerale meststoffen gebruikte was de gemiddelde NO_3^--N concentratie 9 mg per liter. Op de akkerbouwbedrijven die een combinatie van minerale en dierlijke meststoffen gebruikten was de gemiddelde NO_3^--N concentratie 30 mg per liter. Maatregelen die het surplus aan N verlagen en de NO_3^--N concentraties in grond- en drainwater verminderen worden voorgesteld.

1) A similar paper was published in the Proceedings of the International Symposium on 'Nitrates-Agriculture-Water', Paris-Grignon, 1990, 367-374

INTRODUCTION

The increased inputs of organic and inorganic nitrogen (N) on arable land in recent decades has led to raised NO_3^--N concentrations in groundwater pumped from production wells for drinking water. Factors that determine NO_3^--N leaching from agricultural soils are precipitation, soil type, groundwater level (GWL) and management [2,5]. Several measures have been proposed to minimize nitrate leaching from agricultural soils [3]. However, the proposed measures require an adjustment of the management of farms with intensive crop production. Therefore the Netherlands Fertilizer Institute NMI recently started a long-term experiment on intensive crop farms to study the effects of the proposed measures on nitrate leaching and soil fertility and also on crop yield and crop quality. In 1989 a preliminary study was conducted to determine the effects of N input, GWL and soil type on the NO_3^--N concentration of groundwater and drainage water on four intensive crop farms. The results of this study are presented in this paper.

MATERIALS AND METHODS

The study was conducted on four arable farms in the sandy area in the northern part of the Netherlands. The total area of the farms was 189 ha, divided over 32 arable fields. Farm A used only inorganic fertilizers, farms B, C and D a combination of inorganic fertilizers and animal manures. The animal manures were applied to silage maize, potatoes and sugar beet, generally during the winter period. In January 1989, 474 water samples for NO_3^--N analysis were taken from the drains or from the groundwater by using the 'bore hole' method [4]. The bore holes were evenly distribu-

ted over the fields (50x50 m grid). For each sampling point the soil was classified as sandy, peaty, peat or clay, and as one of four groundwaterlevel groups indicating the mean highest GWL, namely 25-40, 40-80, 80-140 and 140-200 cm. For each arable field the surplus of N in 1988 was estimated as the difference between N input and N removal. N input was calculated from data on atmospheric deposition, N fixation by leguminous plants and the recorded use of inorganic fertilizers and animal manures. N fixation was estimated to be 150 kg/ha. The total N input via animal manures was corrected for ammonia volatilization by a factor of 0.8. N removal by crops was estimated from crop yield and mean N content of the crop. The surplus of N at each sampling point in a field was assumed to be equal to the average surplus of N of this field.
The relationship between NO_3^--N concentrations and calculated surplus N, recorded soil type and recorded GWL group were examined for each sampling point, using analysis of variance and multiple linear regression. To execute this statistical analysis it was necessary to transform the NO_3^--N concentrations so as to obtain a normal frequency distribution.
The following linear regression model was used:

$$NO_3^-\text{-N} = A(i,j) * \exp(B*[\text{surplus N}]) \quad (1)$$

where

NO_3-N = nitrate-N concentration in mg/l

A(i,j) = constant, mg/l

$i_{1 \to 4}$ = clay, peat, peaty and sandy soil, respectively

$j_{1 \to 4}$ = mean highest groundwater-level group: 20-40, 40-80, 80-140 or 140-200 cm below the surface

B = estimated coefficient, ha/kg

surplus N = calculated surplus N, kg/ha

RESULTS

On the four farms the sampling points were comparably partitioned over the GWL groups. The mean highest GWL at most sampling points was between 40 and 140 cm. Farms B, C and D had only sandy and peaty soils, farm A had more than 90 percent sandy and peaty soils. No statistically significant differences ($p<0.05$) were found between the NO_3-N concentrations in samples from drainage water and groundwater. Results of the analysis of variance showed a significant effect of surplus N, GWL group and soil type on the NO_3-N concentrations of the groundwater. The linear regression model accounted for 45 percent of the total variance. Differences between the estimates of the four GWL groups and the four soil types were not significant ($p<0.05$). However, NO_3^--N concentration of the groundwater tended to be higher on sandy soils than on peaty, peat and clay soils and tended to increase with a lower GWL.

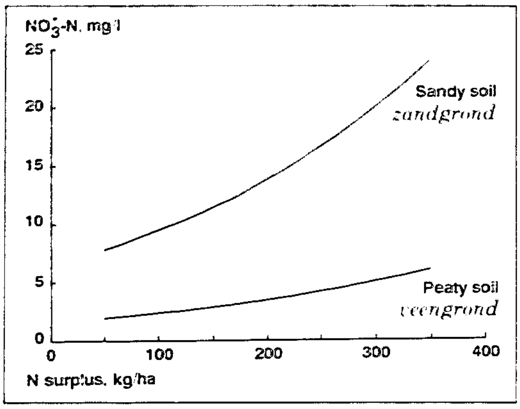

FIGURE 1. Calculated relationship between surplus N and NO_3-N concentration in the shallow groundwater of sandy and peaty soils.
FIGUUR 1. Berekend verband tussen het surplus aan N en de NO_3-N concentratie in het bovenste grondwater van zand- en veengronden.

Figure 1 shows the calculated relationship between the surplus N and the NO_3-N concentration in the shallow groundwater of the sandy and peaty soils. The relationship was calculated with the estimates of the linear regression model.
The mean surplus N on farm A, which used only inorganic fertilizers, was much lower than the mean surplus N on farms B, C and D, which used a combination of inorganic fertilizers and animal manures (Table 1). As a result the mean NO_3^--concentration was about twice as high, the average NO_3^--concentration of the water samples about three times as high and the relative number of samples in which the NO_3^--N concentration exceeded 11.3 mg/l (the EEC standard for drinking water), almost four times as high on (the mean of) farms B, C and D as on farm A.

DISCUSSION

The calculated average amount of surplus N is an estimate of the excess input of N, including any errors in the calculations. All excess N is either stored in the soil through immobilization as organic N, or is lost due to leaching and denitrification. Another part may be lost due to ammonia volatilization; this part would be small, because the animal manures were ploughed in shortly after landspreading. To some extent, the regression model corrected for denitrification and immobilization because groundwater level and soil type strongly affect denitrification and immobilization processes [5].
A significant part of the total variance unaccounted for by the linear regression model may be related to the spatial variability of the surplus N. It is well known that, in actual farming, fertilizers and crop residues are not spread evenly [1].
In this study the NO_3-N concentration of the shallow groundwater from sandy soils exceeded 11.3 mg/l when the calculated surplus N was about 125 kg/ha. This suggests that the

TABLE 1. Calculated surplus N (1), in kg/ha, per crop grown in 1988 and NO_3^--N concentration (2), in mg/l, water samples taken in January 1989 from an arable farm that used only inorganic fertilizers (Farm A) and arable farms that used inorganic and organic fertilizers (Farms B, C and D). The percentage of samples exceeding the EEC standard for drinking water (11.3 mg/l NO_3^--N) is also given.
TABEL 1. Berekende N-surplus (1), in kg/ha, per gewas geteeld in 1988 en de NO_3^--N concentratie (2), in mg/l, van watermonsters genomen in januari 1989. Op een akkerbouwbedrijf dat alleen minerale meststoffen gebruikt (bedrijf A) en akkerbouwbedrijven die een combinatie van minerale en dierlijke meststoffen gebruikten (bedrijven B, C en D). Tevens wordt het percentage overschrijding van de EEG-drinkwaternorm (11.3 mg/l NO_3^--N) gegeven.

Crops in 1988 / *gewassen in 1988*	Farm/*bedrijf*								Mean of farms/ *gem. van de bedrijven* B, C, D	
	A		*B*		*C*		*D*			
	1	2	1	2	1	2	1	2	1	2
Potatoes/*aardappelen*	134	3	240	4	363	38	225	18	276	20
Sugar beet/*suikerbieten*	90	11			229	32	185	33	207	32
Cereals/*granen*	54	5								
Beans/*bonen*	263	47								
Peas/*erwten*					126	23			126	23
Maize/*mais*			251	45	419	49			335	47
Carrots/*penen*	−18	13								
Vetch/*wikke*			360	11					360	11
Mean of the crops / *gem. van de gewassen*	105	16	284	20	284	36	205	26	261	27
Average of all water samples / *gem. van alle watermonsters*		9		23		39		27		30
% samples exceeding EEC standard / *% monsters dat EEG-norm overschreed*		20		60		91		79		77

TABLE 2. N input according to the N fertilizer recommendations in the Netherlands and the calculated surplus N according to equation 2., in kg/ha.
TABEL 2. N-aanvoer volgens het N-bemestingsadvies in Nederland en het berekende N-surplus volgens vergelijking 2., in kg/ha.

Arable crop / *akkerbouwgewas*	N supply / *N-aanvoer*	N surplus, after removal of the / *N-surplus, na afvoer van het*	
		Main product / *hoofdprodukt*	Main product plus by product / *hoofdprodukt plus bijprodukt*
Starch potatoes / *fabrieksaardappelen*	315	165	165
Winter wheat/*wintertarwe*	240	95	75
Spring cereals/*zomergranen*	210	95	75
Sugar beet/*suikerbieten*	240	115	−20
Silage maize/*snijmais*	240	40	40
Beans/*bonen*	340	315	70
Peas/*erwten*	190	10	−80

surplus N on soils that are most sensitive to NO_3^--N leaching should not exceed 125 kg/ha.yr if the NO_3^--N concentrations in the groundwater are to remain below 11.3 mg/l.

In the Netherlands, animal manures are used for their content of phosphorus, potassium and organic matter. When applied before or during winter, the N efficiency of the animal manures is low and unpredictable. Therefore, farmers are reluctant to reduce N application in the form of inorganic fertilizers before sowing or planting their crops. This results in a very high surplus N.

When crops are fertilized according to the current recommendations in the Netherlands, the amount of mineral N in the soil profile during the growing season is sufficient for an optimum crop yield of good quality. When more N is applied than recommended, the risk of NO_3^--N leaching increases [3]. Therefore, adhering to the current N recommendations for arable crops, based on inorganic fertilizers, is a first step toward a reduction in NO_3^--N concentrations in the shallow groundwater without risk of lowering crop yield and crop quality. Table 2 gives the calculated surplus N of common arable crops calculated from equation 2.

Nsur	=	Nreq + Nfix + Ndep − Nrem (2)
Nsur	=	surplus N, kg/ha
Nreq	=	N requirement of arable crops necessary for optimum growth. Calculated with the current recommendations when the mineral N content (Nmin) in spring is set at zero, kg/ha
Nfix	=	N input through N fixation by leguminous crops, kg/ha
Ndep	=	N input due to atmospheric deposition, kg/ha
Nrem	=	N crop removal, kg/ha

The total N input on arable fields is equal to the sum of Nreq, Nfix and Ndep. In the calculations Ndep and Nfix were set at 40 and 150 kg N per ha, respectively. N removal by the main agricultural product without as well as with marketable by-products were included in the calculations.

When starch potatoes, sugar beets and beans are fertilized according to the current recommendations and when the tops are left in the field after harvest, the N surplus still approaches or exceeds 125 kg/ha. The surplus N of these crops may be reduced by removing the tops from the field. When this is not possible, cover crops can be sown to reduce the risk of nitrate leaching.

At present, N fertilization with inorganic fertilizers according to the current recommendations is the best way to reduce NO_3^--N concentrations of the groundwater on farms with intensive crop production. This is confirmed by the results on farm A, where only inorganic fertilizers were used.

CONCLUSIONS

The average NO_3^--N concentration of water samples taken from an arable farm which used only inorganic fertilizers was much lower than that on farms which used a combination of inorganic and animal manures. The NO_3^--N concentration in the water samples was strongly affected by the amount of surplus N. NO_3^--N concentration in the groundwater of soils liable to nitrate leaching did not exceed 11.3 mg NO_3^--N per litre when the surplus N was <125 kg/ha. The surplus N of most arable crops can be reduced to this level by fertilizing the crops according to the N recommendations and by removing not only the main product but also the by-products.

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