RESULTS OF 10 YEARS OF MONITORING NITROGEN IN THE SANDY REGIONS IN THE NETHERLANDS

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ABSTRACT
The effect of policy measures on agriculture and water quality with respect to nitrogen have been monitored on farms in the sandy regions since the early 1990s. Nitrogen surplus on dairy farms decreased by 100 kg/ha (30%) in the 1991-1999 period due to demonstration projects and the implementation of MINAS, limiting farm gate balance surplus. Nitrogen surplus on arable farms has slightly decreased (30 kg/ha, i.e. 20%), probably because MINAS became mandatory for arable farms from 2001 onwards. About 25% of the farm-gate balance N surplus leached as nitrate into the upper metre of the groundwater. The NO_3-N concentration decreased in the 1992-2001 period, but the decrease was larger for dairy farms (16 mg/l, 46%) than for arable farms (7.7 mg/l, 30%). Of the decrease in NO_3-N concentration on dairy farms, 23% is caused by a decrease in N surplus, and 27% by environmental factors, such as a higher precipitation surplus, more wet soils and more peat soils in the second part of the monitoring period. However, unknown factors are responsible for 50% of the decrease.

Keywords :Agriculture; nitrogen use; groundwater quality; nitrate; ammonium; DON

INTRODUCTION
Intensive agriculture in the Netherlands is responsible for large surpluses of nitrogen, the highest of all the member states of the European Union, and phosphorus, the second highest (De Walle and Sevenster, 1998). The legislation on the use of manure, introduced in 1987, limited the application rate of manure in terms of phosphorus, for which the ceilings have become more and more restrictive with time. The effect of the measures was not seen in a reduction in number of livestock, but in the use of feed with a lower phosphate content and manure being transported to stockless arable farms (Neeteson et al., 2001). In 1998 the Netherlands introduced a Mineral Accounting System (MINAS) to limit N applications with manure and artificial fertiliser, as required by the Nitrate Directive as a part of the mineral policy for agriculture (Henkens and Van Keulen, 2001).

It was also decided that the effects of this mineral policy on the environment should be monitored. This led to a scouting programme being carried out in 1987 in the sandy regions. These regions cover about 45% of the acreage for agriculture, where soils are the most vulnerable to nitrate leaching. In 1992 the National Monitoring Programme for effectiveness of the Minerals Policy (LMM in Dutch) started with more permanent and intensive monitoring in the sandy regions (Fraters et al., 2002). In 1993, scouting started in the clay regions, which cover about 40% of the agricultural area. This was followed by intensive monitoring, starting in the autumn of 1996. In the peat regions, covering about 15% of the agricultural area, scouting and monitoring started in the autumn of 1995.

The LMM monitors farm management and water quality. Data from farms are collected to explain or study the relationship between the mineral policy and water quality. Data on environmental factors, e.g. factors influencing the relationship between farm management and water quality, are also collected. Environmental factors are, for example, groundwater regime class, soil type, precipitation and groundwater depth. Peat soils and wet soils are known to have lower nitrate concentrations at nitrogen loads similar to sandy and dry soils (Boumans et al., 2001). After years of showing a high precipitation surplus or in the case of high groundwater table depths, nitrate has been reported to be lower than after years in which the precipitation surplus was low or in the case of low groundwater table depths (Fraters et al., 1998).

The LMM monitors a changing group of farms. Replacement increases variation, making it more difficult to detect changes, and increases costs. Using a changing group has some advantages of overriding importance. First, the sample group will be more representative because the group can be adapted to the dynamics in Dutch agriculture. Second, farms will show less adaptation in farm management– influenced by the fact that they are participants – which introduces bias (Csajabok, pers. comm.). In practice, a fixed group also changes during the period of monitoring because participants will quit for all kinds of reasons and new participants will have to be selected to replace those quitting.

Our purpose here is to present trends in nitrogen surpluses in the sandy regions on the farm-gate balance for 1991-1999 and nitrogen concentrations in upper groundwater for 1992-2001, along with their interrelationships.

METHODS

The sandy regions occur in the eastern, central and southern parts of the Netherlands (see Figure 1). These regions, covering about one-third of the total Dutch territory, were originally oligotrophic. The area under cultivation is about 950,000 ha, while forest and heath cover an area of approximately 287,000 ha.

Farm management characteristics and concentrations in shallow groundwater have been monitored for the two main farm types, dairy and arable, in these regions. A group of other farm types, consisting mainly of factory farms and mixed arable-livestock farms, has also been monitored from 1997. Farms to be monitored here were selected from farms participating in the Farm Accountancy Data Network of the Agricultural Economics Research Institute (FADN; Vrolijk, 2002). FADN comprises about 1500 farms, of which about 20% are replaced each year.

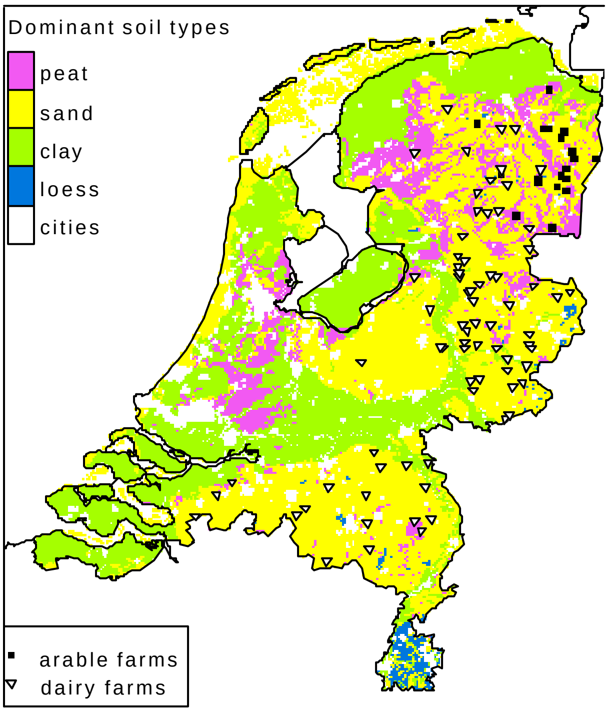

Figure 1: Location of farms sampled in LMM in the1992-1995 period

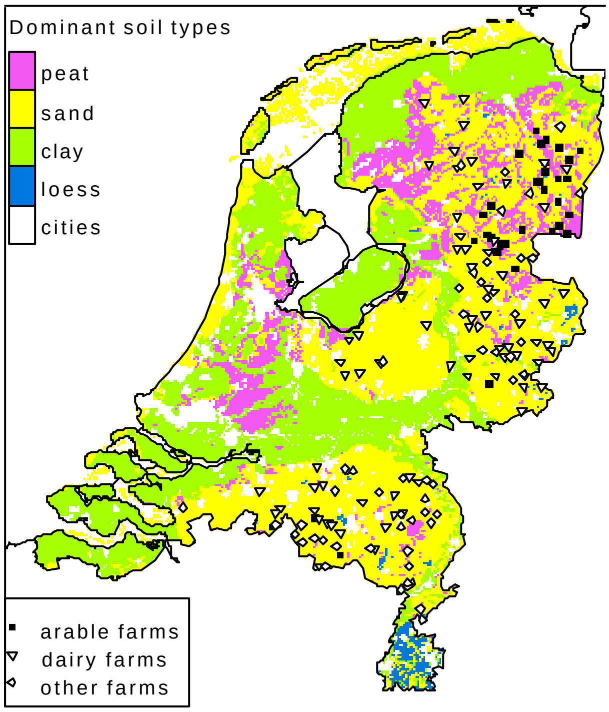

Figure 2: Location of farms sampled in LMM in the1997-2001 period.

A fixed group of about 100 farms was monitored in the 1992-1995 period, called PERIOD 1 (Fraters et al., 1998), Figure 1. A new monitoring programme starting in 1997 monitored the 1997-2001 period, called PERIOD 2, in which a new group of 25-30 farms was selected each year, Figure 2. These groups were and will be monitored for seven years. Each year farm management data were and will be collected. Groundwater was and will continue to be sampled three times during this seven-year period, in the years 1, 4 and 7. A total of 256 different farms were monitored in the 1992-2001 period: at 130 farms groundwater was sampled only once, at 42, twice, at 49, three times and at 35, four times or more. The total number of farm samplings came to 508 in these periods, see **Table 1**.

Table 1: Number of farms samplings in the sandy regions of the Netherlands per year from 1992 to 2001

Farm	1992	1993	1994	1995	1997[@]	1998	1999	2000	2001	Total
Arable	18	19		19	10	10	8	8	10	102
Dairy [#]	75	70	35	66	10	17	13	24	32	342
Other [$]					7	17	21	11	8	64
Total	93	89	35	85	27	44	42	43	50	508

[#] *Dairy farms with and without factory farming.*
[$] *Other farms are mainly factory farms and mixed arable-livestock farms.*
[@] *Due to swine fever, farms with pigs could not be visited.*

Farm management characteristics collected include farm and soil nutrient balance items. Farm data for the year before groundwater was sampled were collected. Therefore the monitoring periods for farm characteristics were set at 1991-1994 and 1996-1999. Data were not yet available for 2000. Both a total farm-gate balance N surplus was calculated for each farm as well as the MINAS N surplus, including stock changes and statutory fixed crop removal for arable crops but without atmospheric deposition.

Groundwater samples were taken from the upper metre of groundwater from April to October. Groundwater sampling points 48 (1992-1994) or 16 (1995 onwards) per farm, were selected and sampled, as described by Fraters et al. (1998). The groundwater was filtered with a 0.45-ìm cellulose nitrate membrane filter then acidified to pH < 2 (H_2SO_4 pro-analysed for NO_3, NH_4, Kjeldahl-N, DOC) with the exception of water for Cl analysis and stored at 4 °C prior to mixing. Individual groundwater samples per farm were mixed, up to 4 samples (1992-1994) or 2 samples (1995 onwards), and then directly analysed. Electric conductivity (EC), pH, and nitrate (Nitrachek Reflectometer) were determined in individual samples in the field. Nitrate and chloride were analysed by ion chromatography using Dionex system 2000i. Kjeldahl-N and ammonium were determined photometrically with Flow Injection Analyses (FIA) (Aquatec Analyser, Tector type 5400), and Kjeldahl-N determined after destruction with sulfuric acid using Foss Tecator tablets with a catalyst. Dissolved Organic Nitrogen (DON) concentration was calculated by subtracting ammonium nitrogen concentration from Kjeldahl-nitrogen concentration. Dissolved Organic Carbon (DOC) was determined with a Phoenix 8000 TOC analyser.

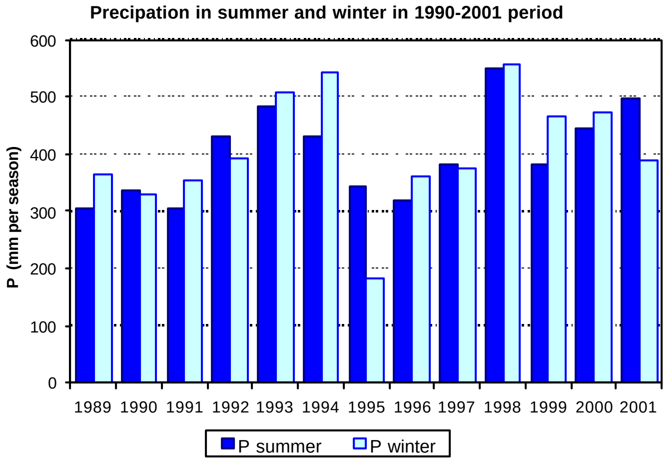

Figure 3: Precipitation (in mm) per year per season in the 1989 – 2001 period. The winter period started in mid-October of the preceding year (Source: Royal Dutch Meteorological Institute).

Precipitation and evapotranspiration data were collected. Total summer and winter precipitation are shown in Figure 3. There were hardly any differences between 1990-1994 and 1995–2000. Index concentrations, indicative for groundwater recharge diluting nitrate, were calculated for each farm sample, as described by Boumans et al. (2001).

Geographical information was collected on soil type and groundwater regime class (GRC) from national maps (see Fraters et al., 1998, for details); fractions per drainage class per year are presented in Figures 4 and 5.. There were, on average, no large differences in fraction of drainage classes between years. Dairy and arable farms participating in the second period had slightly more wet soils and slightly less dry soils than those in the first period, Table 2. Other farms types, only sampled in the second period, showed a higher fraction of neutral and dry soils than dairy and arable farms. There were 2% more peat soils in the second period (26% versus 24%) and 2% fewer clay soils (1% versus 3%), Figure 5.

Differences between farm types and periods were analysed using Turkey's pairwise comparison with a family error rate of 0.05. The Residual Maximum Likelihood method (REML) was used to relate farm mean nitrate concentration to nitrogen surplus, farm mean index concentration (calculated effect of precipitation surplus on quality of the upper metre of groundwater - Boumans et al., 2001), groundwater regime class (GRC), soil type, groundwater table depth and DOC concentration.

Table 2: Fraction of Groundwater Regime Class for each farm type per sampling period

	1992-1995			1997-2001		
	Wet	Neutral	Dry	Wet	Neutral	Dry
All	0.41	0.44	0.15	0.42	0.44	0.14
Dairy	0.42	0.42	0.16	0.49	0.39	0.12
Arable	0.35	0.54	0.11	0.47	0.42	0.10
Other	-	-	-	0.29	0.52	0.19

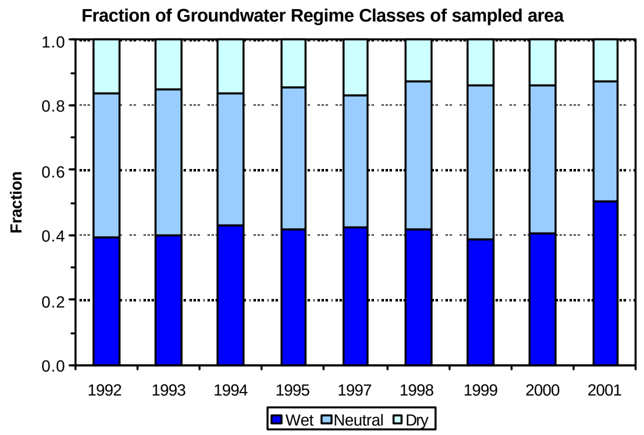

Figure 4: Fraction of groundwater regime classes per area of the farms in the sandy regions sampled in the 1992-2001 period. Data for 2001 are preliminary.

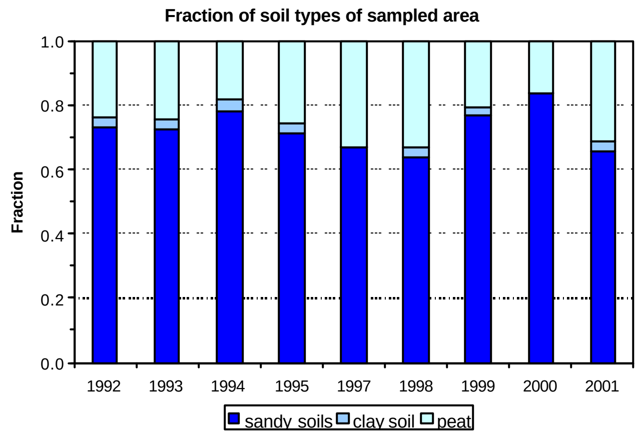

Figure 5: Fraction of soil types per area of the farms in the sandy regions sampled in the 1992-2001 period. Data for 2001 are preliminary.

RESULTS AND DISCUSSION

The nitrogen farm-gate balance and MINAS surplus on dairy farms was found to be higher than on arable farms, see Table 3, Figure 6. For dairy farms the annual average N decreased with about 100 kg/ha between PERIOD 1 and PERIOD 2. This decrease of about 30% was due to such factors as a decrease in use of chemical fertiliser, see Figure 7, and it is assumed to be the result of demonstration projects and the implementation of MINAS (RIVM, 2002). The decrease in N surplus for arable farms was smaller, 30 kg/ha (20%). This was expected because MINAS became mandatory for arable farms only after 2000.

Table 3: Nitrogen farm-gate balance and MINAS surplus (kg/ha) for PERIOD 1 (P1) and 2 (P2). Average values per farm type per period of period average per farm.

		Dairy farms		Arable farms		Other farms
	Source	P1	P2	P1	P2	P2
Supply	Chemical fertiliser	244	208	119	96	113
	Manure, imported	22	15	122	134	40
	Concentrate, roughage, animals	323	309	36	10	1173
	Atmospheric deposition	50	51	42	43	54
	Total supply	639	582	319	283	1381
Removal	Products	137	145	133	126	528
	Manure, exported	51	88	3	0	428
	Total removal	188	234	136	126	953
Farm-gate balance surplus		451	349	183	157	428
MINAS surplus #		337	227	149	115	175

Excluding a/o N deposition, including stock changes and fixed crop removal for arable crops (see Henkens and Van Keulen, 2001)

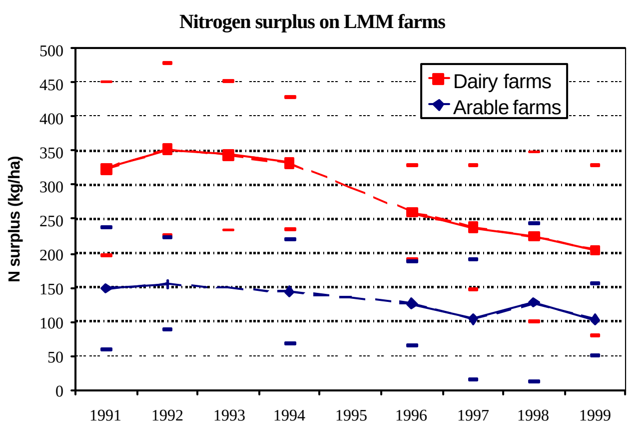

Figure 6: N surplus (MINAS; kg/ha) on LMM farms in the 1991-1999 period, average and standard deviation.

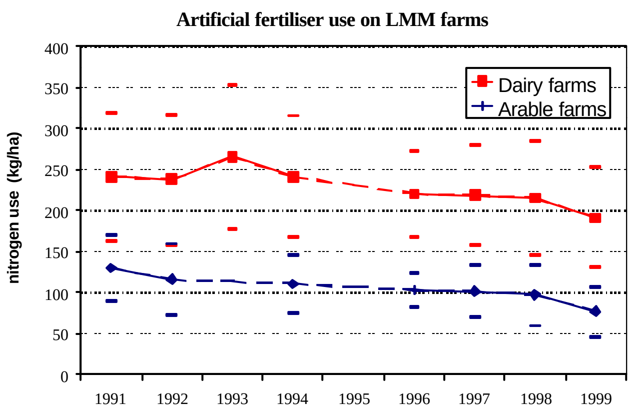

Figure 7: N use with artificial fertiliser (kg/ha) on LMM farms in the 1991-1999 period, average and standard deviation.

Nitrate (NO_3-N) was the major nitrogen compound found in the upper groundwater of farms in the sandy regions, Figure 8, annual average fractions ranging from 0.74–0.85 (data for all N compounds were only available for 1998-2001). Ammonium (NH_4-N) annual average fractions were low (0.05-0.09). Dissolved organic nitrogen (DON) fractions varied from 0.10 to 0.19.

The average NO_3-N concentration in the upper groundwater of farms in the sandy regions in the Netherlands was 34 mg/l ± 3.2 mg/l (95%-confidence limit) for the 1992-1995 period (average of period average per farm). In the 1997-2001 period the average NO_3-N concentration was significantly lower: 23±2.6 mg/l. This decrease was substantial for both dairy farms (see Figure 8) and arable farms (see Figure 9), but larger for dairy farms (16±5.0 mg/l) than for arable farms (7.7±6.1 mg/l). In the first period (1992-1995) the average NO_3-N concentration on arable farms (26±4.6 mg/l) was significantly lower than that on the dairy farms (36±3.8 mg/l). In the second period (1997-2001) the average NO_3-N concentration for arable farms (18±3.6 mg/l) was not significantly lower than that for dairy farms (20±3.5 mg/l). The NO_3-N concentration for both farm types was significantly lower than the average for the other farms (32±5.4 mg/l). Table 4 shows that the NO_3-N concentration of dairy farms continues to decrease, see also Figure 8.

Table 4: Average nitrate concentration (mg/l as NO_3-N) in the upper groundwater of farms in the sandy regions of the Netherlands per farm type per year in the 1992-2001 period[#]

Farm	1992	1993	1994	1995	1997[$]	1998	1999	2000	2001
Arable	30^{a}	33^{a}	-	$14^{a,y2}$	16^{a}	26^{a}	11.4^{a}	17^{a}	19^{ab}
Dairy	45^{b}	44^{b}	21^{y1}	21^{b}	34^{ab}	30^{a}	18^{a}	19^{a}	$13^{a,y3}$
Other	-	-	-	-	48^{b}	43^{a}	26^{a}	26^{a}	28^{b}
Average	42	41	21^{y}	19	31	34^{y2}	21^{y}	21	17

[#]Differences between farm types within the year are significant if letters (a, b) do not match. Significant differences between years are indicated by 'y' , followed by a number with, indicating the value for this year to different from the value indicated for the previous year (1) or number of years ago (2, 3, etc.) if not different from the previous year.
[$]Due to swine fever, farms with pigs could not be visited in 1997.

NH_4-N concentrations were found to be generally low, which is common for dry sandy soils (Clough et al., 1998; Kemppainen, 1995), see Table 5. There was no significant difference in the NH_4-N concentration between the first (0.69±0.21 mg/l) and second (0.78±0.23 mg/l) period or between farm type for either period. DON concentrations were on average 2.8±0.24 mg/l and showed a significant unexplained decrease between 1999 and 2000, see Table 6. They did not significantly differ between farm types. The average DON concentration was somewhat higher than the average 1.9 mg/l in upper groundwater and tile drain water on farms in the clay regions (Fraters et al., 2001), but lower than the average 3.5 mg/l in the upper groundwater on farms in the peat regions (Fraters et al, 2002).

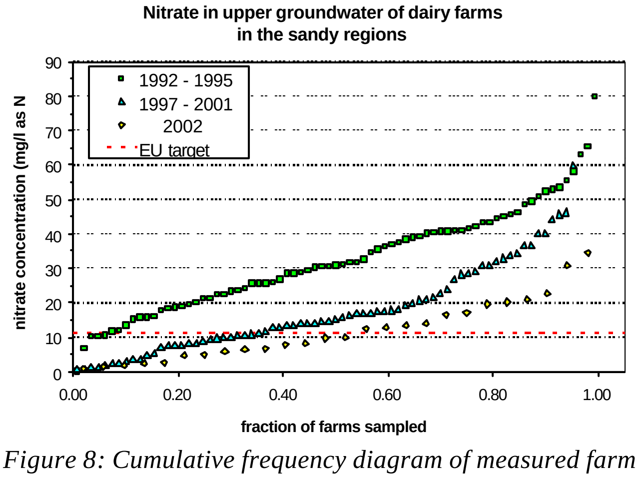

Figure 8: Cumulative frequency diagram of measured farm period average nitrate concentrations in the upper groundwater of dairy farms in the sandy regions of the Netherlands in the 1992-1995 and 1997-2001 periods, and 2002.

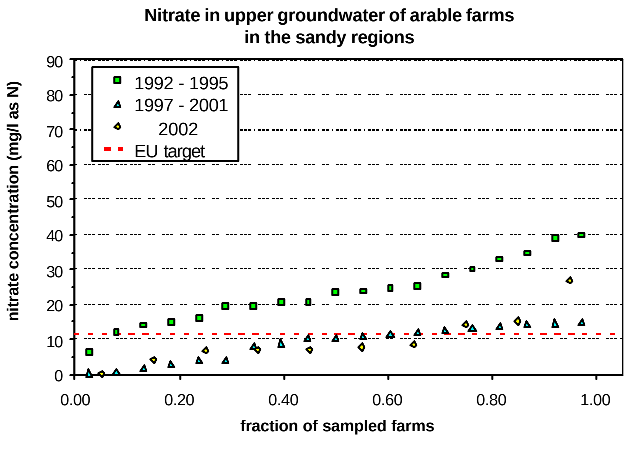

Figure 9: Cumulative frequency diagram of measured farm period average nitrate concentrations in the upper groundwater of arable farms in the sandy regions of the Netherlands in the 1992-1995 and 1997-2001 periods, and 2002.

Table 5: Average ammonium concentration (mg/l as NH_4-N) in the upper groundwater of farms in the sandy regions of the Netherlands per farm type per year in 1992-2001 period#

Farm	1992	1993	1994	1995	1997$	1998	1999	2000	2001
Arable	-	0.89^{a}	-	0.29^{a}	1.48^{a}	1.25^{a}	0.90^{a}	0.89^{a}	1.07^{a}
Dairy	-	0.81^{a}	0.79	0.67^{a}	0.33^{a}	0.61^{a}	0.80^{a}	0.51^{a}	0.78^{a}
Other	-	-	-	-	0.32^{a}	0.53^{a}	0.46^{a}	1.79^{a}	0.95^{a}
Average	-	0.83	0.79	0.58	0.75	0.72	0.65	0.91	0.86

#, $ See note # and $ in Table 4

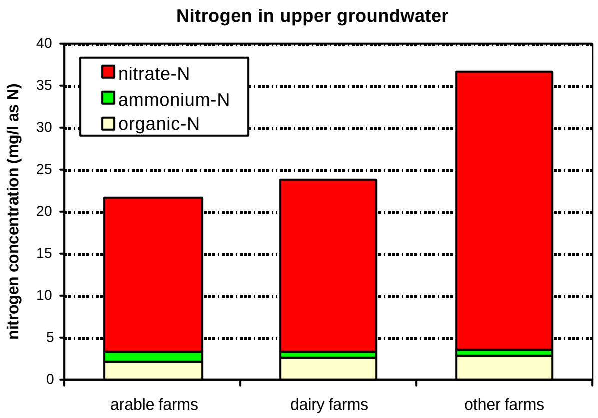

Figure 10: Nitrogen compounds per farm type in upper groundwater of LMM farms in the sandy regions in the 1998-2001 period.

Table 6: Average dissolved organic nitrogen concentration (DON in mg/l as N) in the upper groundwater of farms in the sandy regions of the Netherlands per farm type per year in 1998-2001 period#

Farm	1998	1999	2000	2001
Arable	2.4^{a}	3.0^{a}	2.0^{a}	2.0^{a}
Dairy	2.9^{a}	3.0^{a}	2.7^{a}	2.6^{a}
Other	3.4^{a}	3.5^{a}	2.0^{a}	1.7^{a}
Average	3.0	3.3	2.4^{y}	2.4

See note # in Table 4

The 46% decrease in nitrate in upper groundwater of dairy farms between periods is probably also influenced by environmental factors; a decrease was also observed for arable farms. There was no clear difference in the precipitation between the two periods, Figure 3. Nevertheless, groundwater table depths were slightly, but significantly, lower in the second period (P1: 1.26±0.07 m versus P2: 1.39±0.09 m), see Table 7. There was no significant difference between the two periods (P1: 1.26±0.09 m, P2: 1.29±0.13 m) for dairy farms, but arable farms had a significantly lower groundwater table depth in the second period (P1: 1.11±0.09 m and P2: 1.44±0.17 m). Although deeper groundwater table depths could indicate dryer circumstances, the calculated index concentrations show that nitrate might have been slightly, more diluted in the second period (P1: 1.24±0.05 and P2: 1.12±0.06; a figure of 1.00 for the index, corresponding with a precipitation surplus of 360 mm). Groundwater regime class (Figure 4) and soil type (Figure 5) might have had some influence on the concentration, because there were somewhat more wet soils and peat soils in the second period.

Table 7: Average groundwater table depth (in metres below surface level at time of sampling) on farms in the sandy regions of the Netherlands per farm type per year in the 1992-2001 period#

Farm	1992	1993	1994	1995	1997$	1998	1999	2000	2001
Arable	1.41^{a}	1.38^{a}	-	$0.57^{a,y2}$	$1.68^{a,y}$	1.28^{a}	1.47^{a}	1.41^{a}	1.39^{a}
Dairy	1.51^{a}	1.36^{a}	1.20^{y2}	$0.92^{b,y}$	$1.73^{a,y}$	$1.10^{a,y}$	1.34^{a}	1.18^{a}	1.24^{a}
Other	-	-	-	-	1.40^{a}	1.41^{a}	1.66^{a}	1.32^{a}	1.65^{a}
Average	1.49	1.36	1.20	0.84^{y}	1.63^{y}	1.26^{y}	1.56	1.25	1.33

#, $ See note # and $ in Table 4

Not only NO_3-N, but also chloride (Cl), showed a decrease of 27% in concentration in the upper groundwater between the first (41±2.8 mg/l) and second periods (31±1.7 mg/l), see Table 8. This decrease occurred both on arable and dairy farms. There was no significant difference in Cl concentration between farm types in either period. This common decrease might be due to increased precipitation, i.e. dilution. But it could also be due to a decrease in load. For chloride no data are yet available to underpin a change in load, via e.g. potassium fertiliser or manure.

Table 8: Average chloride concentration (mg/l) in the upper groundwater of farms in the sandy regions of the Netherlands per farm type per year in 1992-2001 period[#]

Farm	1992	1993	1994	1995	1997[$]	1998	1999	2000	2001
Arable	51[a]	50[a]	-	23[a,y2]	35[a,y]	48[a,y]	27[a,y]	27[a]	29[a]
Dairy	50[a]	46[a]	32[y]	31[a]	37[a]	40[ab]	36[a]	28[a]	23[a,y3]
Other	-	-	-	-	46[a]	34[b]	28a,y2	36[a]	29[a]
Average	50	47	32[y]	29	39[y]	39	30[y]	30	24

[#, $] See note # and $ in Table 4

DOC concentration increased from 22±2.8 mg/l in the first period to 33±3.7 mg/l in the second, with a lower groundwater table depth. This increase occurred on both arable and dairy farms. DOC concentrations were generally higher on arable farms than on dairy or other farms, see Table 9. This is due to arable farms commonly occurring on former peat soils in the northern part of the country, see Figures 1 and 2. The higher DOC concentration in the second period could at least be partly due to the slightly higher fraction of peat soils in the second period. DOC is assumed to reflect soil organic matter content (Kalbitz and Geyer, 2002). A higher DOC concentration is related to lower nitrate concentration (Pearson correlation: -0.37, $p<0.00$).

Table 9: Average dissolved organic carbon concentration (DOC in mg/l) in the upper groundwater of farms in the sandy regions of the Netherlands per farm type per year in 1992-2001 period[#]

Farm	1992	1993	1994	1995	1997[#]	1998	1999	2000	2001
Arable	32[a]	32[a]	-	-[3]	36[a]	33[a]	42[a]	37[a]	35[a]
Dairy	17[b]	19[b]	33	26[&]	22[a]	29[a]	37[a,y5]	31[a]	36[a]
Other	-	-	-	-	19[a]	37[a]	31[a]	28[a]	24[a]
Average	20	22	33	26	26	34[y4]	35	32	34

[#, $] See note # and $ in Table 4.

[&] Groundwater samples from arable farms and from 29 of the 37 dairy farms were not analysed for DOC.

Accounting for net precipitation, on average 98 kg/ha of NO_3-N was leached to the upper groundwater in PERIOD 1 and 75 kg/ha in PERIOD 2. This is 25% and 23% of the farm-gate balance surplus in PERIOD 1 and PERIOD 2, respectively. The average farm-gate balance surplus on farms in the sandy regions should be lower than 150 kg/ha to achieve an average NO_3-N concentration of less than 11.3 mg/l, for environmental and agronomic conditions as encountered in the 1992-2001 period.

The statistical model showed an effect of 3.5 ± 0.6 mg/l of NO_3-N per 100 kg of nitrogen MINAS surplus. This small effect might be due, for example, to a lag time between change in surplus and change in nitrate concentration. The change in N surplus of 34 and 110 kg/ha, as calculated for arable farms and dairy farms, respectively, between the two periods would result in a change of 1.2 and 3.7 mg/l in NO_3-N concentration, respectively. Although the model accounted for all known environmental factors, an unexplained decrease of 8 mg/l of NO_3-N remained for dairy farms. So only a decrease of about 4 mg/l could be ascribed to differences in environmental factors between the two periods. These differences were as shown very small. The unexplained decrease will be a subject for further study, indicating as it does a model mis-specification with respect to both farm management and environmental factors.

CONCLUSIONS

Nitrate in the upper groundwater of dairy farms in the sandy regions of the Netherlands has decreased by 16 mg/l (46%) between 1992-1995 and 1997-2001. Of this decrease, 23% is due to a decrease in nitrogen surplus of 100 kg/ha between the two periods and 27% to environmental factors, such as a higher dilution due to a slightly increased precipitation surplus and a higher denitrification due to a higher fraction of peat soils and wet soils. Fifty per cent of the decrease is caused by unexplained influences. The decrease in the nitrate concentration of 7.7 mg/l (30%) on arable farms between the two periods is due a decrease in surplus (15%) and to environmental factors and unexplained influences.

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