Nitrate-N Accumulation in the Soil Profiles of Long-term Fertilizer Experiments

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Introduction

One of the most important environmental problems both in the developed and developing countries is the increasing nitrate contents of the surface and subsurface waters, which are the drinking water reservoirs. The investigation of the origin of the nitrate found in different depths of the soil profile or in the groundwater showed that it may come from various polluting sources, such as industrial and communal establishments, animal husbandry and fertilizer storage, but it may also take its origin from the mineralization of organic N-forms, geochemical processes, leaching and transport by precipitation and surface waters. Fertilization with organic and mineral fertilizers also play a part in this process (DEBRECZENI 1992; NÉMETH & BUZÁS, 1990).

Nitrate pollution in the soil and in the groundwater may originate from point or non-point sources. Over-fertilization and the improper use of fertilizers on arable land involves the hazard of contaminating the environment, causing non-point source pollution. To understand the role of fertilization in this harmful process, and to investigate the fate and behaviour of nitrogen in the soil-plant-water system, long-term field experiments are one of the best tools. In recent years long-term experiments have been carried out for this purpose all over the world (ADDISCOTT et al., 1991; CAMPBELL et al., 1983; HOFMAN et al., 1981) and also in Hungary (NÉMETH & BUZÁS, 1985; NÉMETH, 1993, 1994; NÉMETH et al., 1987-1988).

Materials and Methods

The experimental series chosen for the present measurements, started in 1968 at 9 experimental stations in different parts of the country, on different soil types, under diverse environmental conditions (supervised by the Pannon Agricultural University, Keszthely).

In the first four cycles (1968/69 - 1983/84) winter wheat, maize, maize and winter wheat were grown, while in the following cycle the plant order was winter wheat, maize, sunflower and winter wheat (1st deep-drilling), then winter wheat, maize, maize, winter wheat and winter wheat (2nd deep-drilling). The basic soil analysis data of this network were published by DEBRECZENI (1992) and DEBRECZENI & DEBRECZENI (1994).

Deep-drilling was carried out at 8 experimental stations in July 1988 and at 9 stations in July 1993, following the harvest of winter wheat. Soil samples were taken from the unfertilized plots and from plots which received 0, 50, 150 and 250 kg N/ha/year each, in four replications. Deep-drilling penetrated to a depth of 3 meters and samples were taken every 20 cm.

From the samples the soil moisture contents were determined immediately, while the mineral-N and other chemical analyses were carried out after air-drying.

In this paper the results of the soil moisture and nitrate-N analyses of two experimental sites (Kompolt: chernozem brown forest soil, Hajdúböszörmény: meadow soil) from the above-mentioned 9 experimental stations are presented.

Results

Kompolt Experimental Station

The soil type of the experimental site is chernozem brown forest soil with a high clay content (40-48%). The upper 35 cm is dark brown loamy clay; between 35 and 70 cm there is black clay; from 70 down to 220 cm the clay is dark brown, while below 220 cm until 300 cm the clay is light brown. The pH is characteristically very low (pH_{KCl} = 4.0-4.7). The depth of the humus layer is 80 cm; the hydrophysical properties of this soil are unfavourable. The yearly precipitation, averaged over the experimental years (1968-1987), was 547 mm.

At the first sampling date the hand boring technique was used and unfortunately, because of the heavy texture, it was not possible to drill down to 3 metres on each plot. This is why soil moisture results are only available at this date from the upper 100 cm soil layer.

Soil moisture content. - On Figure 1 the soil moisture contents (w%) of the different soil layers are shown. It can be seen that, because of the drought between the two sampling dates, there is a significant soil moisture decrease in the upper 100 cm soil layer. The precipitation was 50 mm/year less on the average of the last 5 years compared to the mean of the experimental years (HOLLÓ, 1994). The drought was serious in 1992 (322 mm - a decrease of 225 mm) and till the sampling date in 1993 (only 127 mm precipitation occurred between January and mid- July in that year).

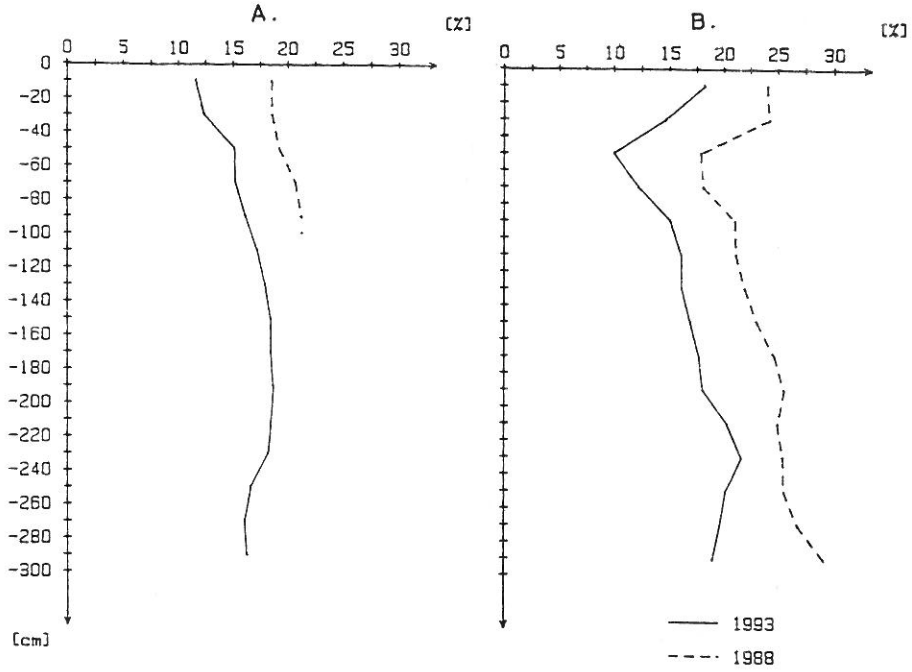

Figure 1
Soil moisture content (w%) in the chernozem brown soil, Kompolt (A) and meadow soil, Hajdúböszörmény (B)

Nitrate-N content. - Because of the above mentioned drilling problem in 1988, samples for the nitrate-N analyses could only be obtained from the upper 0-100 cm soil layers, except from plots which received 250 kg N/ha/year, where it was possible to drill down to 200 cm. In the first three treatments the nitrate-N concentration was under 10 mg/kg in the whole depth, while after the yearly application of 250 kg N/ha the nitrate-N content exceeded this value at below 60 cm. There were no accumulation peaks in the profiles, however this value of over 10 mg/kg value existed in the whole 200 cm depth.

In 1993, with the machine drilling technique, it proved possible with some difficulty to reach a depth of 300 cm on all plots. In profiles treated with 0 and 50 kg N/ha/year the nitrate-N concentrations were similar to each other; no nitrogen excess was detected in the deeper layers. After the yearly application of 150 and 250 kg N/ha, nitrogen accumulation occurred in the profiles, and the differences between the treatments remained in the whole drilling depth. The mean nitrate-N contents (mg/kg) in the soil profiles of differently fertilized plots were 3.6 - 3.3 - 12.4 - 22.5, with a statistically significant difference of 3.8 (Table 1). Statistical analyses on the results also show that there are significant differences between an annual 150 kg N/ha and the lower rates, as well as between an annual 250 kg N/ha and the three other treatments in the mean of the whole profile.

As mentioned above, deep-drilling was carried out in both years in July, after the harvest of winter wheat. Comparing the nitrate-N concentrations at the two sampling dates, it can be seen that in 1993 differences were detected between the treatments even in the upper soil layers where they were not detectable 5 years earlier. This is because of the drought in the period between the two samplings, the precipitation was less than average, and it was not enough either to achieve satisfactory yields or to leach the surplus nitrogen to the deeper horizons.

Hajdubószörmény Experimental Station

The soil type is meadow soil, with a medium (35%) clay content. The main texture category in the profile is loamy clay. The upper 30 cm soil layer is black, with a high organic matter content; down to 80 cm it is grey with a higher clay content. Between 80 cm and 180 cm it is silty, with gravel below 100 cm and some Mn and Fe concretions. Below 200 cm the texture is the same with strong Mn, Fe and lime concretions and gravel, with gley in the deepest 30-40 cm layer. The pH is neutral or slightly acid; the depth of the groundwater table is 250-300 cm. The depth of the humus layer is 50 cm. This soil has a moderate infiltration rate, permeability and hydraulic conductivity, with high field capacity. The yearly precipitation averaged over the first 20 years was 538 mm.

Soil moisture content. - On Figure 1 the soil moisture content of the 300 cm soil layer is shown for 1988 and 1993. From the figure it can be concluded that, as the result of the drought between the two sampling dates, a significant soil moisture decrease occurred in the whole profile. As mentioned above, the 20-year mean precipitation at this location was 538 mm. The yearly precipitation data of the next period, between the two deep drilling dates (1988 and 1993), show a significant decrease, with the lowest amount (267.6 mm/year) in 1992. The 5-year average precipitation was 132 mm lower than the previous 20-year mean (SÁRVÁRI, 1994). In both years deep-drilling revealed a minimum value in the soil moisture content of this meadow soil at a depth of 40-60 cm, because of the water utilization of the cultivated plants.

Nitrate-N content. - The results of the first deep-drilling show that there was no nitrate-N accumulation in the profiles of the N-control plots or in plots which received 50 kg N/ha/year nitrogen fertilizer. After the 20-year applica-

Table 1

Nitrate-N concentration (mg/kg) in the soil profiles of the chernozem brown forest soil (Kompolt)

Depth, cm	1988						1993					
	Applied N (kg/ha/year)				$LSD_{5\%}$	Mean	Applied N (kg/ha/year)				$LSD_{5\%}$	Mean
	0	50	150	250			0	50	150	250		
0-20	6.9	5.3	7.1	5.2		6.1	10.2	11.0	19.5	32.3		18.3
20-40	3.6	3.8	3.5	4.3		3.8	5.1	6.0	16.1	28.0		13.8
40-60	4.0	1.5	5.0	7.5		4.5	1.7	2.6	12.7	28.9		11.5
60-80	0.6	1.1	9.0	11.0		5.4	5.1	0.9	6.8	19.5		8.1
80-100	3.0	3.0	7.5	12.2		6.4	0.0	5.1	13.6	14.4	10.7	8.3
100-120	-	-	-	10.9		10.9	1.7	3.4	17.0	21.2		10.8
120-140	-	-	-	13.8		13.8	5.1	3.4	14.4	22.9		11.5
140-160	-	-	-	13.8		13.8	1.7	2.6	16.1	22.9		10.8
160-180	-	-	-	16.0		16.0	1.3	-	11.9	22.9		9.0
180-200	-	-	-	14.9		14.9	6.8	1.7	15.3	22.9		11.7
200-220	-	-	-	-		-	3.4	6.0	11.9	24.6		11.5
220-240	-	-	-	-		-	5.1	6.0	7.6	20.4		9.8
240-260	-	-	-	-		-	3.4	0.9	5.1	18.7		7.0
260-280	-	-	-	-		-	3.4	0.9	11.0	20.4		8.9
280-300	-	-	-	-		-	-	-	6.8	17.0		5.9
$LSD_{5\%}$			5.1			5.1			9.9			5.2
Mean	3.6	2.9	6.4	11.0		-	3.6	3.3	12.4	22.5	3.8	10.5
0-100	3.6	2.9	6.4	8.0		5.2	4.4	5.1	13.8	24.6		12.0
100-200	-	-	-	13.9		13.9	3.3	2.2	15.0	22.6		10.8
200-300	-	-	-	-		-	3.1	2.7	8.5	20.2		8.6

Table 2

Nitrate-N concentration (mg/kg) in the soil profiles of the meadow soil (Hajduböszörmény)

Depth, cm	1988						1993					
	Applied N (kg/ha/year)				$LSD_{5\%}$	Mean	Applied N (kg/ha/year)				$LSD_{5\%}$	Mean
	0	50	150	250			0	50	150	250		
0-20	6.5	4.5	6.0	6.6		5.9	11.9	13.6	22.2	30.7		19.6
20-40	5.6	3.9	5.8	5.5		5.2	5.1	6.0	8.5	26.5		11.5
40-60	1.7	3.7	3.1	5.0		3.4	10.3	7.7	27.3	33.3		19.6
60-80	2.6	3.0	9.5	25.8		10.2	1.7	3.4	28.9	61.5		23.9
80-100	3.1	3.2	16.2	48.8		17.8	1.7	1.7	45.1	117.8		41.6
100-120	5.6	2.8	18.1	38.8		16.3	6.8	4.3	46.1	102.4		39.9
120-140	2.3	2.5	9.3	23.2	6.2	9.3	3.4	-	27.3	63.9	18.5	23.7
140-160	3.1	4.9	6.4	14.3		7.2	1.7	1.7	2.0	34.1		15.1
160-180	3.0	5.4	7.5	10.3		6.5	1.7	1.7	14.5	20.5		9.6
180-200	2.9	3.9	5.7	8.0		5.1	2.7	5.1	14.5	15.4		9.4
200-220	-	-	3.2	4.8		4.0	3.4	3.4	11.9	11.9		7.7
220-240	-	-	3.8	5.0		4.4	-	8.5	7.7	6.0		5.5
240-260	-	-	4.2	2.4		3.3	6.8	5.1	3.4	4.3		4.9
260-280	-	-	5.1	5.4		5.3	-	2.6	6.8	6.0		3.8
280-300	-	-	3.9	1.9		.,9	1.7	3.4	7.7	4.3		4.3
$LSD_{5\%}$			4.7			3.3			14.7			7.8
Mean	3.6	3.7	7.2	13.7	5.2	7.1	3.9	4.5	19.7	35.9	11.4	16.0
0-100	3.9	3.6	8.1	18.3		8.5	6.1	6.5	26.4	53.9		23.2
100-200	3.4	3.9	9.4	18.9		8.9	3.3	2.6	25.1	47.2		19.5
200-300	-	-	4.0	3.9		4.0	2.4	4.6	7.5	6.5		5.2

tion of 150 and 250 kg N/ha/year, nitrate-N accumulation could be found between 50 and 175 cm. The peak of accumulation is around 100 cm. Practically no nitrogen was found in the form of nitrate below 200 cm.

After 5 years, at the time of the next sampling, it could be concluded that the trend in nitrate-N accumulation and distribution in the profiles was the same as the previous one (i.e. 1988), especially in the control and the lowest application rate plots, where the amount of nitrate-N was the same in the deep-drilling profiles. By contrast, more nitrogen was found in the form of nitrate in the profiles of plots fertilized with 150 kg N/ha and 250 kg N/ha, than at the first sampling date, but this increase did not change the depth of the accumulation peak. The difference between the nitrate-N contents of the soil profiles was 240 kg at the two sampling dates in the 150 kg N/ha/year treatments and 430 kg in the 250 kg N/ha/year treatments.

In 1993 the differences in the nitrate-N content between the treatments could be observed in the upper part of the soil profiles as well as in Kompolt. This was because of the drought and the lower uptake of the winter wheat plants.

This study was supported by the National Scientific Research Fund (OTKA) Grant No. T 006563.

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