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Nitrate-N in the Soil Profiles of Long-term Field Experiments

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After the growing season, part of the nitrogen remains in forms sensitive to changes in conditions, such as nitrate. In years with above-average precipitation a significant amount of nitrate can leave the rooting zone of various crops even when land is cropped annually. Integration of knowledge related to environmental conditions of a certain area with the soil, water, and crop management practices helps in preventing the simultaneity of unfavourable processes leading to nitrate leaching, thus water resources may be protected from nitrate pollution of agricultural origin.

When nitrogen originating from various sources is introduced into the soil N pool, the concentrations of the various N forms will increase via several N transformation processes. After the growing season, part of the nitrogen remains in nitrate form, which is sensitive to changes in the conditions. Consequently, because of these changes, these N forms may result in environmental hazards (leaching, denitrification, etc.). Nitrate leaching from the rooting zone depends on soil texture, several N transforming processes, fertilizer inputs, plant uptake of N, precipitation, evaporation and evapotranspiration. On areas which are characterized by frequent moisture deficits, it is usually assumed that nitrate leaching is unlikely to occur. Basically this is true, but in years with above-average precipitation a significant amount of nitrate can leave the rooting zone of various crops even when land is cropped annually (CAMPBELL et al., 1983; KÁDÁR & NÉMETH, 1993). Generally and particularly in the above-mentioned situation, leaching occurs when N is found as nitrate in the unsaturated zone, and simultaneously there is enough water to wash through the root zone. This is the reason why in most cases when agriculture was indicted for causing nitrate pollution, it has been due to poor soil, water and crop management practices (CAMPBELL et al., 1994; FOLLETT, 1989; NÉMETH, 1993, 1994). Knowing the environmental conditions of a certain area helps to avoid the simultaneity of unfavourable processes leading to nitrate leaching.

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Residual nitrogen may remain in the form of nitrate in profiles of many soils under Hungarian environmental conditions (negative water balance, deep groundwater table, migration type soils, etc.). The surplus N, in the form of NO_3-N, may accumulate in the profile or may be leached to deeper soil layers, or to the groundwater, depending on the physical characteristics of the soil and on environmental conditions. If the peak of NO_3-N accumulation remains in the rooting zone, this N can be taken up by the crops, satisfying their N demands. Mineral-N fertilization recommendation systems are based on the determination of this N (the NO_3-N, or NO_3-N plus exchangeable NH_4-N) content of a certain soil layer. For the better understanding of the role of mineral-N in the nutrition of cultivated plants, it is necessary to investigate the fate and behaviour of these N forms, more specifically to study the accumulation, distribution and movement of NO_3-N in different soil profiles. In case the N fertilizer recommendation is based on field experiments in which the fertilizer response is well calibrated, this part of the previously surplus N should also be taken into consideration. Proper crop rotations including deep-rooted scavenger plants like winter oil-seed rape, alfalfa, sunflower and safflower are needed to utilize this nitrogen.

Materials and Methods

Long-term N fertilization experiments were established with identical treatments in two different growing areas in Hungary: one on a calcareous sandy soil (Őrbottyán) and the other on a calcareous chernozem soil (Nagyhörcsök). The aim was to create differences in the mineral-N content of soil profiles in order to determine their N supplying capacity and to decide whether the accumulated nitrate may be regarded as a supply index for crop production. In the first three years of the experiments four rates of fertilizer-N were established. In the fourth year (1988) the original plots were divided into five smaller ones onto which five spring fertilizer levels were applied. In this fourth year winter oil-seed rape was the indicator plant. In the following three years the basic four N fertilizer treatments were applied again, and in the eighth year (1992) a division of the plots was made similarly to the fourth year with five spring N fertilizer levels applied to each original plot. This time the indicator plant was winter wheat. In the following this 4-year-step was replicated (in 1996 with spring barley as test plant). The effects of residual-N and of freshly applied fertilizer-N on the yield of winter oil-seed rape, winter wheat and spring barley were compared.

The results showed that under certain environmental conditions N may accumulate in the soil profile in the form of nitrate, resulting from N fertilization in previous years, to such an extent that it must be taken into consideration when determining the fertilizer rates to be applied. This is important not only from the point of view of economical management and environment protection, but also for reaching better yield quality. The calculations can be reliably performed if they are based on the measurement and calibration of the soil's mineral-N content.

Soil and meteorological features

Őrbottyán: The long-term (100 years) average precipitation in this region is 500 mm, the climate can be characterized as continental. The soil type – according to the Hungarian soil classification – is calcareous sandy soil, with 3–6% $CaCO_3$, 0.9–1.1% organic matter and 800–1200 mg total N/kg in the ploughed layer; the C/N ratio is 7.5–8.0. The humuous layer is 20–60 cm thick. According to soil analyses the soil's pH (KCl) is 7.0–7.3; the AL(ammonium-lactate)-soluble P_2O_5 and K_2O contents are 70–80 and 50–80 mg/kg, respectively. These results indicate that the soil's original nutrient supply is medium-to-weak. The average level of the groundwater table is around 270–320 cm.

Nagyhörcsök: This site has a yearly mean temperature of 10.9 °C and a long-term (100 years) average precipitation of 550–580 mm; the climate is continental. The soil type is calcareous chernozem (formed on loess parent material) with loamy soil texture. The main characteristics of the ploughed layer are: $CaCO_3$ content: 5%, organic matter: 3%, total-N 2100–2200 mg/kg, C/N ratio: 7.7–8.5. The thickness of the humuous layer is 75–90 cm. According to soil analyses the pH(KCl) is 7.2–7.3; the AL-soluble P_2O_5 and K_2O contents are 60–80 and 140–160 mg/kg. These results show that the original P supply is weak, while the K supply is medium. The average level of the groundwater table is around 13–15 m.

Treatments

Large (250 m²) plots were set up, with 4 N fertilizer rates (0, 150, 300 and 450 kg N/ha/year) in 4 replications in the autumn of 1984. The rate of phosphorus (100 kg active ingredients/ha) and potassium (200 kg active ingredients/ha) were the same in all N treatments. The mineral-N content of the profiles of these 16 large plots were checked in spring and in autumn every year, just before fertilization. Mineral-N analyses were made by the methods of BREMNER and KEENEY (1966).

These experiments were used in 1988 (indicator plant: winter oil-seed rape) in 1992 (winter wheat) and in 1996 (spring barley) to compare the effect of residual nitrogen to spring applied nitrogen during the calibration.

In 1987, after the harvest of the previous crop (spring barley) and the sampling for mineral-N analyses, the scheduled autumn fertilization was applied. In the spring of 1988, after soil sampling for mineral-N analyses, the large (250 m²) plots were divided into 5 subplots, and the spring N fertilization was applied in rates of 0, 50, 100, 150 and 200 kg N/ha on these small (50 m²) plots.

Using these treatment combinations 80–80 subplots (4 main treatments, 5 spring fertilization levels, 4 replications) were investigated at the two experimental sites. The large plots were divided in the same way and a similar fertilization procedure was repeated in 1992, and in 1996 as well.

Deep-drilling (down to 3 m) was carried out in 1997 spring to study the fate and distribution of residual nitrogen in the form of nitrate along the soil profile. Drilling was carried out on the main plots preceding spring N application, in four replications. Soil samples were taken from the unfertilized plots and plots receiving 150, 300 and 450 kg N/ha/year each, in four replications. The depth of deep-drilling was 300 cm, and samples were taken after every 20 cm. Both ammonium-N and nitrate-N were determined, and the soil moisture content was also measured. The soil moisture contents of samples were measured immediately, while the mineral-N and other chemical analyses were conducted after air-drying the samples.

Results and Discussion

Soil moisture content

From long-term meteorological observations it can be recognized that the last few years period was drier than the long-term averages. The annual precipitation measured directly at the Research Stations (average of the last 5 years between 1992–1996) was as follows: Őrbottyán: 467 mm; Nagyhörcsök: 444 mm, while on the average of 36 years, the yearly precipitation values are 583 mm for Őrbottyán and 541 mm for Nagyhörcsök.

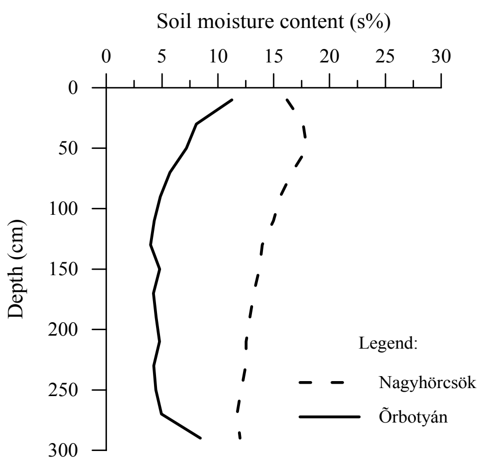

Figure 1
Soil moisture content (s%) in the soil profiles

In Figure 1 the soil moisture contents of the different soil layers are shown at both locations. In the calcareous sandy soil the moisture content was lower in the whole profile than in the chernozem profile. In the sandy soil profile the moisture content decreased down to 150 cm, below this depth there was no change in moisture content till 300 cm (less than 5 s%), while in the chernozem profile the peak of moisture content was observed at the 50 cm depth.

Nitrate-N accumulation

In previous studies it was found that under similar experimental conditions the surplus N could be detected only in the form of nitrate-N (NÉMETH & BUZÁS, 1991; SARKADI et al., 1986). The ammonium-N content of soils did not vary with different N application rates.

The nitrate-N content of the differently fertilized plots in 1997 can be seen in Tables 1 and 2. The results of the deep-drillings at Őrbottyán (sandy soil) and Nagyhörcsök (chernozem soil) show that no nitrogen accumulation occurred in the profiles of the unfertilized (N-control) plots.

Őrbottyán. – There were only slight nitrate-N accumulations in the sandy soil profile following the yearly application of different N doses. The average nitrate-N measured in the 300 cm deep profiles was 4.18 mg/kg in the control

Table 1

NO_3-N content (mg/kg) in the sandy soil profile (Őrbottyán)
Sampling date: 2 April, 1997 (average of 4 replications)

Depth, cm	N dose, kg/ha/y				$LSD_{5\%}$	Average
	0	150	300	450		
0–20	0.8	3.3	7.4	5.0		4.13
20–40	7.4	5.8	3.3	6.6		5.78
40–60	4.1	5.0	14.9	14.9		9.70
60–80	3.3	6.6	15.7	16.5		10.52
80–100	8.3	7.4	11.6	10.7		9.49
100–120	5.0	3.3	11.6	13.2		8.26
120–140	1.7	6.6	3.3	9.9		5.37
140–160	3.3	5.0	9.9	3.3		5.36
160–180	5.8	2.5	5.0	9.1		5.57
180–200	1.7	2.5	4.1	6.6		3.71
200–220	2.5	9.1	7.4	2.5		5.37
220–240	4.1	2.5	4.1	8.3		4.75
240–260	2.5	3.3	0.8	6.6		3.30
260–280	5.8	3.3	0.8	1.7		2.89
280–300	6.6	3.3	7.4	4.1		5.37
$LSD_{5\%}$						3.74
Average	4.18	4.62	7.15	7.92	2.81	5.97

plots, 4.62, 7.15 and 7.92 mg/kg in the 150, 300 and 450 kg N/ha/year treatments, resp. On the average of the 300 cm soil layers there were significant differences ($LSD_{5\%}$) between the control and the yearly applied 300 and 450 kg/ha nitrogen treatments.

When calculating only the nitrate-N amount measured in the upper 100 cm, it can be seen that more nitrogen remained in the form of nitrate in this layer (4.78, 5.62, 10.58 and 10.74 mg/kg nitrate-N, resp.), than in the deeper ones.

Nagyhörcsök. – More nitrate-N can be found in the profiles of the chernozem soil after the yearly application of different N doses than in the sandy soil. On the average in the 300 cm deep soil profile, 6.99 mg/kg nitrate-N was measured in the the control plots, 15.68 mg/kg in the 150 kg/ha, 35.61 mg/kg in the 300 kg/ha, and 42.37 mg/kg in the 450 kg N/ha/year treatments, resp. On the average in the 300 cm soil layers, there were significant differences ($LSD_{5\%}$) not only between the control and the yearly applied 300 and 450 kg/ha N treatments, but also between the yearly application of 150, 300 and 450 kg/ha N. The differences between the 300 and 450 kg/ha/year treatments were not proven to be significant.

Table 2
NO_3-N content (mg/kg) in the chernozem soil profile (Nagyhörcsök)
Sampling date: 3 April, 1997 (average of 4 replications)

Depth, cm	N-dose, (kg/ha/y)				*$LSD_{(5\%)}$*	Average
	0	150	300	450		
0–20	13.2	12.4	9.9	9.1		11.15
20–40	14.0	9.9	23.1	18.2		16.30
40–60	9.1	14.9	56.1	33.0		28.27
60–80	9.1	14.0	42.1	26.4		22.91
80–100	5.0	14.0	18.2	31.4		17.13
100–120	3.3	12.4	16.5	32.2		16.10
120–140	6.6	6.6	17.3	22.3		13.21
140–160	7.4	9.1	28.1	18.2		15.68
160–180	4.1	12.4	19.8	23.9		15.06
180–200	5.8	18.2	33.0	33.8		22.70
200–220	0.8	18.2	37.1	44.6		25.18
220–240	6.6	17.3	43.8	65.2		33.23
240–260	5.8	25.6	50.4	78.4		40.04
260–280	8.3	29.7	62.7	94.1		48.70
280–300	5.8	20.6	75.9	104.8		51.80
$LSD_{(5\%)}$						*9.49*
Average	6.99	15.68	35.61	42.37	*13.39*	25.16

On this well-drained, loamy soil, where the average depth of the groundwater table is 13–15 m, more nitrogen can be found in the deeper layers than in the upper 100 cm in the profiles of the over-fertilized plots (300 and 450 kg N/ha/year). There are two peaks of nitrate-N in the profiles of these over-fertilized plots, the first can be found between 40–60 cm, while the second at the deepest measured layer (280–300 cm).

On the basis of these long-term nitrogen studies N fertilization experiments were carried out to compare the residual effects of the previous N fertilization with spring (fresh) N fertilization. The aim of this study was to measure, calculate and calibrate the soil mineral-N content, ensuring better utilization of the residual N, and to determine the amount of N to be applied for optimum yield at different residual N levels. As it was mentioned, in four-year-steps winter oilseed rape (1988), winter wheat (1992), and spring barley (1996) were the test plants, respectively. The results show that there was a significant correlation between the amount of residual nitrogen and the obtained yield in all cases (NÉMETH, 1996).

Summary

Long-term N fertilization experiments were established with identical treatments at two different growing areas in Hungary: one on a calcareous sandy soil (Őrbottyán) and the other on a calcareous chernozem soil (Nagyhörcsök). The aim was to create differences in mineral-N content in the soil profiles in order to determine their N supplying capacity and to establish whether the accumulated nitrate may be regarded as a supply index for crop production.

The results showed that under certain environmental conditions N may accumulate in the soil profile in the form of nitrate, resulting from N fertilization in previous years, to such an extent that it must be taken into consideration when determining the fertilizer rates to be applied. This is important not only from the point of view of economical management and environment protection, but also for reaching better yield quality. The calculations can be reliably performed if they are based on the measurement and calibration of the soil's mineral-N content.

The environmental importance of such calibration experiments is that by estimating the utilization of N from the mineral-N pool, the additional costs incurred due to over-fertilization can be eliminated, and at the same time the potential danger of NO_3 leaching to the groundwater can be reduced. Extrapolation of the experimental results to farm scale can lead to both economical and environmental achievements.

Key words: residual N, N fertilization, field experiments, nitrate accumulation

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