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DYNAMICS OF NITRATE LEACHING FROM SOILS IN A LYSIMETRIC EXPERIMENT IN 1991-1994

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A b s t r a c t. The aim of the present research started in 1977 as a lysimetric experiment in the Institute of Soil Science and Plant Cultivation in Puławy, was, among others, determination of the leaching dynamics for plant nutrients as related to type of soil and level of NPK fertilization. To this end, determination of soil water balance, changes in the chemical composition of the lysimetric filtrates and level of ion leaching during consecutive months and years of the the experiment.

In the conditions of the present lysimetric experiment, effects of season, type of soil and plants on the amount of filtrates collected was observed. Nitrate concentration in the filtrates was related to the kind of soil, its utilization and fertilization level. Nitrate concentration in the water percolating through the fallow soil, particulary loess and loamy soils, was usually higher than the water from the cultivated soils. There was no effect (similarly to the previous years) of the fertilization level on the nitrate ions losses from the soil. The highest amount of nitrogen was lost from the fallow soil (the mean of 9.3-14.2 g m^{-2} $year^{-1}$).

K e y w o r d s: lysimeters, nitrate, dynamics, concentration, leaching.

INTRODUCTION

Nutrients which were not taken up by plants or adsorbed by the soil complex, may be transferred with rainfall down the soil profile to the ground water. It is necessary to protect water against pollution. Hence, there is a need to evaluate mineral component penetration from the soil to the ground water as a result of percolation.

There are a lot of methods to evaluate this process. One of them is a lysimetric experiment which has not been often applied in our country.

The aim of the present research started in 1977 as a lysimetric experiment in

the Institute of Soil Science and Plant Cultivation in Puławy, was, among others, determination of the leaching dynamics for plant nutrients as related to type of soil and level of NPK fertilization. To this end, determination of soil water balance, changes in the chemical composition of the lysimetric filtrates and level of ion leaching during consecutive months and years of the the experiment.

METHODS

Investigations were conducted in 1991-1994 at the Institute of Soil Science and Plant Cultivation in Puławy.

Concrete lysimeters (1 m^2 surface area, 1.4 m depth) were filled with three different kinds of soil: brown soil developed from loamy sand, brown soil developed from loess, and grey-brown soil developed from light loam on heavy loam. Soil materials were put into the lysimeters following the natural genetic horizons. Plants were cultivated in the following four-year cycles: potato, spring barley, winter rape and winter wheat. Three rates of mineral NPK fertilizers (simple, double and triple), liming, and bare fallow without any fertilization as a control, were applied in this experiment. For more details on the method see previous papers [4,5].

Soil filtrates were collected to polyethylene containers. Once a month, after weighing, the filtrate samples and rainfall samples were collected, and the NO_3^- concentration was determined with the colorimeric method by means of phenolodisulphonic acid.

RESULTS

Lysimetric filtrates

In this paper monthly means from the period 1991-1994 for the filtrates and rainfalls amount were presented. These results are the basis for the evaluation of the dynamics of NO_3^- ions leaching from the soil. The highest amount of rainfall was noted from May to October (Table 1). Comparing monthly mean levels of rainfall and lysimetric filtrates, it can be noted that the amount of water percolated through the soil is sometimes bigger than the amount of rainfall. It was observed in March for the cultivated soils and in December, January and March for the bare fallow soils (Table 4). It was the effect of such factors as low evaporation, subsoil freezing, heavy rainfall in the last days of the month. Hence, rainfall water was only partly infiltrated. During an intensive vegetation period from May to September, the amount of filtrates from the cultivated soil was minimum (loamy soil) or it

Table 1. Percolating water as a percentage of rainfall in the cultivated plots

Month	Rainfall (mm)	Soil								
		sandy			loess			loamy		
		1	2	3	1	2	3	1	2	3
XI	43	32.5	29.0	34.1	18.8	9.5	11.8	34.3	20.0	15.3
XII	35	49.7	52.3	55.4	44.0	36.1	31.5	77.8	62.2	56.5
I	25	82.2	64.8	65.6	45.5	39.5	32.4	109.1	84.2	54.9
II	27	16.8	20.9	16.8	18.7	2.6	4.9	36.6	44.0	22.0
III	36	122.8	118.9	109.7	103.1	75.3	83.6	142.5	127.5	119.2
IV	44	63.0	62.8	61.4	45.1	51.0	54.2	80.6	65.5	66.8
V	47	8.5	6.8	6.8	-	-	-	7.7	5.1	5.5
VI	60	1.8	0.8	1.0	-	-	-	3.3	2.8	2.8
VII	38	-	-	-	-	-	-	1.8	1.1	0.8
VIII	54	-	-	-	-	-	-	0.6	-	-
IX	73	-	-	-	-	-	-	8.2	1.2	-
X	55	24.3	11.3	15.7	4.0	-	-	27.8	19.0	-

1,2,3 - level of NPK fertilization.

was total inhibition of percolation (loess soil and sandy soil). Incraesing levels of fertilization did not have any significant influence on the amount of filtrates received from the particular soils. Comparison of filtrate amounts from the individual objects that the highest amount of filtrates in a year was collected from the bare fallow soils. The monthly means were from 5.0 to 145.6% of rainfalls from the loess soil, 19.4 to 129.2% from the loamy soil and from 20.5 to 1611% from the sandy soil (Table 4). During the year, from 14.4 to 36.2% rainfall water percolated on the average through the cultivated soils. Percolating through the bare fallow soils was higher and it was from 48.2 to 67.7% (Table 5a).

Concentration of nitrate ions

Nitrates are the main component of water pollution in the agricultural areas. Results obtained from the lysimetric experiment showed that there was a high probability of nitrate anion transfer with the filtrates. Monthly means of $N\text{-}NO_3^-$ concentration calculated for the period 1991-1994 (Table 2) show that there is relation between the concentration of this nitrogen form in the filtrates and the kind of soil. During those years, the lowest concentration of nitrate ions was found in the filtrates from the cultivated loess soil and the highest from sandy soil. Among the bare fallow soil objects, the highest concentration of nitrates was found in the filtrates from loamy soil. Concentration of nitrate ions in the water flowing out from the fallow loess plots and loamy soil was always higher than in the filtrates

Table 2. Concentration of nitrate ions (mg/dm^3) in the cultivated plots

Month	Soil								
	sandy			loess			loamy		
	1	2	3	1	2	3	1	2	3
XI	45.7	57.6	59.9	8.0	12.2	23.5	12.8	18.9	21.2
XII	37.7	42.4	42.1	7.1	8.7	19.4	17.2	21.5	25.6
I	35.6	38.4	41.6	9.6	8.5	20.7	23.3	29.6	27.0
II	46.7	58.9	57.8	7.0	14.3	23.1	23.5	24.6	33.9
III	40.3	50.7	46.1	15.9	15.1	24.3	25.5	23.1	30.1
IV	29.0	32.7	31.6	31.0	31.4	25.6	26.6	20.7	36.1
V	27.5	37.5	40.6	-	-	-	19.4	20.8	23.1
VI	36.4	30.0	50.0	-	-	-	25.0	20.6	17.6
VII	-	-	-	-	-	-	14.3	12.5	16.7
VIII	-	-	-	-	-	-	8.3	-	-
IX	-	-	-	-	-	-	11.7	11.1	-
X	36.1	37.1	45.3	2.3	-	-	23.7	25.0	-

1,2,3 - level of NPK fertilization.

Table 3. Leaching of nitrate ions ($g\ m^{-2}$) in the cultivated soils

Month	Soil								
	sandy			loess			loamy		
	1	2	3	1	2	3	1	2	3
XI	0.64	0.72	0.88	0.06	0.05	0.12	0.19	0.17	0.14
XII	0.66	0.78	0.82	0.11	0.11	0.21	0.47	0.47	0.51
I	0.74	0.63	0.69	0.11	0.08	0.17	0.64	0.63	0.37
II	0.21	0.33	0.26	0.03	0.01	0.03	0.23	0.29	0.20
III	1.78	2.17	1.82	0.59	0.41	0.73	1.31	1.06	1.29
IV	0.81	0.91	0.86	0.62	0.71	0.61	0.95	0.60	1.07
V	0.11	0.12	0.13	-	-	-	0.07	0.05	0.06
VI	0.04	0.01	0.03	-	-	-	0.05	0.03	0.03
VII	-	-	-	-	-	-	0.01	0.01	0.01
VIII	-	-	-	-	-	-	0.01	-	-
IX	-	-	-	-	-	-	0.07	0.01	-
X	0.48	0.23	0.39	0.01	-	-	0.36	0.26	-

1,2,3 - level of NPK fertilization.

from the cultivated plots. Seasonal changes were not observed. Nitrates are transferred to the water with rainfall or due to the mineral changes of organic matter in the fallow conditions. In the objects, where the highest fertilization doses were applied, a tendency to increase concentration of nitrate ions was observed in the filtrates from the objects of the NPK II sandy soil and NPK III loess and loamy soils

Table 3a. Leaching of ^{15}N from the soil (% of rate)

Years	Level of fertilization	1st year	2nd year	3rd year	4th year	Sum
			Sandy soil			
1991-1994	I	0.25	0	1.28	1.64	3.17
	II	0.29	0	1.59	1.74	3.62
1992-1995	I	0	2.53	6.12	0.21	8.86
	II	0	0.12	1.80	0.07	1.99
1993-1996	I	4.10	7.50	0.24	0.08	11.92
	II	4.42	6.77	0.35	0.18	11.72
			Loess soil			
1991-1994	I	0	0	0.11	0.08	0.19
	II	0	0	0.29	0.40	0.69
1992-1995	I	0	0.97	2.70	0	3.67
	II	0	0.71	1.53	0	2.24
1993-1996	I	1.39	1.68	0	0	3.07
	II	1.86	2.05	0	0	3.91

Table 4. Percolating water, concentration and leaching of nitrate ions from the fallow soils

Month	Precipitation (mm)	Percolate % precipitation			Concentration (mg dm^{-3})			Leaching (g m^{-2})		
		P	L	G	P	L	G	P	L	G
XI	43	83.8	59.6	59.6	48.2	39.7	55.3	1.74	1.02	1.42
XII	35	107.4	105.4	95.7	40.7	36.4	42.4	1.54	1.35	1.43
I	25	137.9	125.7	120.2	41.5	32.7	37.8	1.45	1.04	1.15
II	27	57.5	35.4	53.0	51.9	35.8	44.4	0.80	0.34	0.63
III	36	161.1	145.6	129.2	47.2	32.6	41.7	2.74	1.71	1.94
IV	44	89.8	80.0	70.9	34.2	43.6	47.1	1.36	1.56	1.48
V	47	26.6	8.5	1.4	36.8	37.5	39.6	0.46	0.15	0.36
VI	60	36.1	13.4	31.7	42.1	30.0	45.3	0.91	0.24	0.86
VII	38	44.1	5.0	44.6	26.3	42.1	32.5	0.44	0.08	0.55
VIII	54	20.5	-	27.1	19.1	-	33.1	0.21	-	0.48
IX	73	60.4	31.4	43.9	30.4	28.1	47.4	1.35	0.65	1.53
X	55	65.3	53.6	47.7	32.5	37.5	48.7	1.16	1.10	1.27

P - sandy soil; L - loess soil; G - loamy soil.

as compared to the NPK I objects. For example, the mean concentration of nitrate nitrogen in March, in the filtrates from the sandy soil NPK I objects was 40.3 mg dm^{-3} (Table 2), while from the NPK II objects - 50.7 mg and NPK III - 46.1 mg. In the filtrates from the loess soil NPK I objects, concentration of nitrate ions was (in the same month) 15.5 mg N- NO_3^- dm^{-3} from NPK II objects - 15.3 mg and from NPK III objects 24.3 mg N dm^{-3}. A similar regularity was observed for the

Table 5a. Percolating water as a percentage of rainfall, sum for the year

Year	Rainfall (mm)	Cultivated plots									Fallow plots		
		P			L			G			P	L	G
		1	2	3	1	2	3	1	2	3	1	2	3
1991	425	30.0	26.1	28.4	18.9	21.4	24.1	33.9	27.7	30.6	53.4	27.4	43.9
1992	568	7.2	10.6	10.6	-	0.2	-	19.0	13.5	5.8	71.3	48.4	58.6
1993	489	41.9	39.1	40.0	32.2	27.1	26.8	49.8	42.2	38.1	76.3	51.9	60.0
1994	668	32.4	25.7	24.2	23.9	12.6	12.9	42.3	32.7	21.6	67.5	58.4	57.9
Sum	2150	-	-	-	-	-	-	-	-	-	-	-	-
Mean	537	27.4	24.8	25.0	18.5	14.4	14.9	36.2	28.8	23.0	67.7	48.2	55.8

P - sandy soil; L - loess soil; G - loamy soil; 1,2,3 - level of NPK fertilization.

Table 5b. Concentration of nitrate ions (mg dm^{-3}), mean values for the year

Year	Cultivated plots									Fallow plots		
	P			L			G			P	L	G
	1	2	3	1	2	3	1	2	3	1	2	3
1991	21.1	23.7	26.1	7.7	9.5	18.4	19.8	17.5	18.0	21.6	13.5	15.2
1992	50.2	56.9	55.4	-	7.7	-	22.5	17.1	16.3	52.9	26.2	47.3
1993	40.9	43.5	47.2	17.2	18.4	26.3	16.5	19.9	30.0	41.8	57.3	64.9
1994	40.7	54.3	48.7	18.1	25.9	38.5	29.2	31.6	43.3	32.8	35.1	38.2
Mean	37.2	44.3	43.8	15.7	17.8	27.0	22.5	23.2	29.8	38.9	35.7	43.7

Table 5c. Mean leaching of nitrate nitrogen (g m^{-2}) in a year

Year	Cultivated plots									Fallow plots		
	P			L			G			P	L	G
	1	2	3	1	2	3	1	2	3	1	2	3
1991	2.70	2.63	3.15	0.62	0.86	1.88	2.85	2.06	2.35	4.90	1.57	2.84
1992	2.06	3.42	3.32	-	0.01	-	2.43	1.31	0.54	21.41	7.19	15.74
1993	8.36	8.30	9.21	2.71	2.44	3.44	4.01	4.11	5.59	15.57	14.55	19.02
1994	8.82	9.31	7.87	2.89	2.18	3.31	8.24	6.90	6.25	14.80	13.71	14.78
Sum	21.94	23.66	23.55	6.22	5.49	8.63	17.53	14.38	14.73	56.68	37.02	52.38
Mean	5.49	5.92	5.89	1.56	1.37	2.16	4.38	3.60	3.68	14.17	9.26	13.10

loamy soil filtrates. The filtrates from the NPK I plots contained 25.5 mg of N-NO_3^-, from NPK II plots - 23.1 and from NPK III plots - 30.1 mg dm^{-3}. The lots-30.1 mg dm^{-3}. The annual means of nitrate nitrogen concentration in the investigated period (Table 5) pointed out to an increasing tendency observed together with an increase in the fertilizer rates, particulary in the case of filtrates from the loess and loamy soils. For the sandy soil with the lowest NPK fertilization rate, concentration

of nitrate ions was 37.4 mg, while with the highest rate, 43.7 mg $N\text{-}NO_3^-$ dm^{-3} and was similar to the NPK II - 44.1 mg. High concentration of nitrates for the filtrates from the loamy soil was observed, however, it was significantly lower than for the sandy soil, i.e.: for the NPK I objects - 22.2 mg dm^{-3}, for the NPK III objects - 30.1 mg N dm^{-3}. A similar tendency was noted for the filtrates from the loess soil. They had lower concentration of nitrates than the filtrates from the sandy and loamy soils. Also in this case a long-term and diversified fertilization influenced concentration of NO_3^- ions. Nitrates concentration in the filtrates from the NPK I objects was 15.7 mg, while from the NPK III - 24.2 mg $N\text{-}NO_3^-$ dm^{-3}. An increase in the mean N concentration of the filtrates together with an increasing NPK fertilization rate is not statistically confirmed.

Nitrate leaching

Nitrate leaching (a product of filtrate concentration and amount), was very differentiated in the present lysimetric experiment during the whole year. This was also related to the kind of soil and object fertilisation. The lowest nitrogen losses by leaching were noted for the loess soil. Twice or triple higher losses were observed for the loamy and the sandy soils. During the year, the highest leaching was observed in March. This was obviously related to the highest amount of filtrates in that period. The annual means of nitrogen losses from the cultivated soils were: (in g m^{-2} $year^{-1}$) in the loess soil 1.37-2.16, loamy soil 3.60-4.38 and from sandy soil 5.49-5.92. What was even more significant, nitrogen penetration to the soil water was: 9.26 g from the loess soil, 13.10 g from the loamy soil and 14.17 g m^{-2} $year^{-1}$ from the sandy soil in the fallow objects (Table 5c). On the basis of the present lysimetric experiment carried out in 1991-1996 on the sandy and loess soil (NPK I and NPK II objects) with the application of double $^{15}NH_4{}^{15}NO_3$ labelling as a fertilizer, we can conclude that the amount of nitrogen fertilizer which was leached in the four-year period was for the sandy soil from 2.0 to 12.0% of the dose, while for the loess soil, from 0.2 to 3.9% of the applied dose. The highest losses were noted during rape cultivation, from November 1992 to April 1993 and during wheat cultivation, in the spring of 1994.

DISCUSSION

Among numerous problems related to fertilization, determination of losses in the mineral components as a result of leaching from the soils are of particular economic and practical importance. Level of leaching from the soil is the product of

the initial ion concentration and amount of infiltrating water. In the lysimetric experiment conducted in 1991-1994, contribution of filtrates in relation to rainfall water was at the level of 7.2 to 41.9% for the sandy soil, 0 to 33.2% for the loess soil and 5.8 to 49.8% for the loamy soil in the cultivated plots. For the soils from the fallow plots, it was higher, i.e.: 53.4-76.3%, 27.4-58,4% and 43.9 to 60.0%, respectively.

The above data confirms findings from other papers [1,3,7,8,11] and results received by the present author in 1978-1989 [9]. Concentration of mineral components in the soil filtrates results from many soil processes wich are modified by weather condition and agricultural factors. In this experiment, nitrate concentration in the filtrates from the cultivated soils was from 2.3 to 59.9 mg dm^{-3} and was related to the type of soil. Our investigation point out that there is significant effect of organic matter mineralization on the concentration of nitrate ions in the filtrates. The above finding was confirmed by the $N\text{-}NO_3^-$ concentration in the filtrates from the fallow lysimeters plots that ranged from 19.1-55.3 mg N dm^{-3}. These values were similar to the results by other autors for both lysimeric and drain water [2,3,10]. Our investigation showed that in spite of an increasing tendency in concentration level of nitrate ions as results of higher doses of fertilizers, the total amount of nitrate nitrogen leached from the NPK III object was lower or similar to the level observed for the lowest level of NPK fertilization. It was caused by a higher N uptake and higher amount of water used by the plants growing with better nitrogen supply conditions.

CONCLUSIONS

1. In the conditions of the present lysimetric experiment, effects of season, type of soil and plants on the amount of filtrates collected was observed.

2. Nitrate concentration in the filtrates was related to the kind of soil, its utilization and fertilization level.

3. Nitrate concentration in the water percolating through the fallow soil, particulary loess and loamy soils, was usually higher than the water from the cultivated soils.

4. There was no effect (similarly to the previous years) of the fertilization level on the nitrate ions losses from the soil. The highest amount of nitrogen was lost from the fallow soil (the mean of 9.3-14.2 g m^{-2} $year^{-1}$).

REFERENCES

1. **Amberger A., Schweiger P.:** Substanzproduktion und Sicherwassermengen verschiedener Boden in langjahrigen Lysimeterversuch. Bayer. Landwirtsch. Jahrbuch, 55(6/78), 714-726, 1978.

2. **Kjellerup V., Dam Kofoed A.:** Nitrogen fertilization in relation to leaching of plant nutrients from soil lysimeter experiment with ^{15}N. Tiddsskr. Planteavl., 87, 1-22, 1983.
3. **Low A.J., Armitage E.R.:** The composition of the leachate trough cropped and uncropped soils in lysimeters compared with that of the rain. Plant Soil, 33, 393-411, 1970.
4. **Miller M.H.:** Contribution of nitrogen and phosphorus to subsurface drainage water from intensively cropped mineral and organic soil in Ontario. J. Environ. Quality, 8(1), 42-48, 1979.
5. **Ruszkowska M., Rębowska Z., Sykut S., Kusio M.:** Nutrient balance in lysimeter experiment (1977-1981). I. Balance of nitrogen, phosphorus and potasium. Pam. Puł., 82, 7-28, 1984.
6. **Ruszkowska M., Warchołowa M., Rębowska Z., Sykut S.:** Nutrient balance in lysimeter experiment (1977-1981). II. Balance of calcium, magnesium and sulphur. Pam. Puł., 82, 29-50, 1984.
7. **Sapek B., Pietrzak S.:** Application of porous ceramic cups method to estimate the potential nitrate leaching from the grassland soils. Zesz. Probl. Post. Nauk Roln., 440, 343-352, 1996.
8. **Smoroń S., Kopeć S., Misztal A.:** The dynamics of nitrates in filtrating waters accompanying different agricultural crops. Zesz. Probl. Post. Nauk Roln., 440, 367-374, 1996.
9. **Sykut S.:** The dynamics of the leaching process from soil in a lysimeter experiment. I. Anions. Pam. Puł., 103, 11-35, 1993.
10. **Szymańska H., Kostrzewa S.:** Chemistry of drainage waters in conditions of differentiated fertilization. Symp. "Chemical composition of soil, ground and surface waters in conditions of intensive agricultural production". Falenty, IUNG, Puławy, I, 143-147, 1984.
11. **Vomel A.:** Der Nahrstoffumsatz in boden und Pflanze auf grund von Lysimeterversuchen. Fortschr. Acker-u. Pflanzenbau, 3, 1-95, 1974.