Influence of acidification on the leaching of nutrients in lysimeter experiment

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Key words

acidification, lysimeter experiment, nutrients leaching from soil.

Summary

The effect of soil acidification on the leaching of nutrients (N-NO_3, K^+, Ca^{2+}, Mg^{2+}) in soil was studied on the basis of a lysimeter experiment which included a sandy soil, a loess soil and a loamy soil. After long-term (started at 1977) application of mineral fertilizer (NPK vs. NPK+Ca), soil acidification of the non-limed and a fallowed treatments increased. The aim of the study was to compare the nutrient amount and concentration in lysimeter leakages between objects with diversified pH. It was found that acidification and kind of soil influenced the nutrients leaching from soil.

Introduction

One of the most essential indicators of soil environment quality is the acidification degree; this determines direction and intensity among many soil processes. Nitrogen and potassium fertilization is the most important anthropogenic factor of acidification in agricultural soils [FILIPEK et al., 1998; GOULDING and BLAKE, 1998a]. Excessive soil acidification develops a level of disadvantageous changes in chemical, physical and physico-chemical properties of the soil, as well as soil microbiological activity weakness [HELYAR and PORTER, 1989]. A yield decrease in acidic soils is frequently connected with the limitation of nutrients available for plants due to leaching and/or immobilization [HAYNES and SWIFT, 1986]. The aim of this study was to compare the nutrients amount and concentration in lysimeter leakages between treatments with diversified pH. Lysimeter experiment results were compared with laboratory experiment results.

Material and Methods

A lysimeter experiment has been carried out in the Institute of Soil Science and Plant Cultivation (IUNG) at Pulawy. The experiment consisted of 70 concrete lysimeters 1m² in area and 1.3 m deep. The inside of the lysimeters was coated with an epoxy resin. Lysimeters were filled with 3 soils with a natural layout of genetic horizons preservation: a brown soil developed from sand, a brown soil developed from loess, and a grey-brown soil developed from loam. Plants were cultivated in a four-course rotation, where potato, spring barley, winter rape and winter wheat were included. The rotation scheme was repeated in the following years. The whole experiment included 3 fertilization levels NPKMg, farm yard manure fertilization of potatoes, liming before barley cultivation every 4 years, and fallowed, non-fertilized soils. In this publication the data from 3 treatments is presented only: 1) Double NPK rates without liming, 2) Double NPK rates with liming according to 0.5 - 0.75 Hh, 3) Fallowed, non-fertilized soil. In treatments 1 and 2 fertilization was applied: 200 kg N . ha^{-1} as ammonium nitrate, 80 kg P . ha^{-1} as granulated superphosphate, 80 kg K . ha^{-1} as potassium chloride and 24 kg Mg . ha^{-1} as magnesium sulphate. The crops were harvested at full maturity. Soil leachates were collected into polyethylene cans and were weighed once a month (or more frequently) as the cans were filled. Average samples of leachates and precipitations were taken once a month too. The samples were analyzed for N-NO_3, K^+, Ca^{2+} and Mg^{2+} contents. Each year, after the crop harvest, representative samples of the soils were collected from a depth of 0-30 cm. In soil samples pH in 1 mol . dm^{-3} KCl, hydrolytic acidity and the content of exchangeable cations were analyzed. The content of nitrate nitrogen was measured by the colorimetric method, the content of calcium and potassium using the F-AES method (flame atomic emission spectrometry) and magnesium by the F-AAS method (flame atomic absorption spectrometry). The analyses were carried out by Central Laboratory IUNG at Pulawy.

For the laboratory experiment, 4 kg total weight average soil samples were taken from 0-20 cm layout from 4 different soils. A soil material was sifted through a plastic sieve with a mesh size of 1 mm. The experimental unit was 250 g of soil sample in a plastic cup. Different values of pH which are occurring in Polish soils (pH_{H2O} : 3.5 - 7.5) were simulated in these samples. Simulation of pH was carried out by the addition of NaOH (1 mol . dm^{-3}) and HCl (1 mol . dm^{-3} and 0.1 mol . dm^{-3}) as well as by maintaining a 60% full water capacity for 6 months. Proper amounts of sodium hydroxide and hydrochloric acid were determined by buffer capacity of the soil. After incubation, under room conditions with a temperature of 20°C, single-time nutrients extraction was carried out by a 1 hour shaking of the soil material with redistilled water in a ratio of 1 to 10 (soil to water). The soil-water mixture was filtered under pressure and the content of N-NO_3, K^+, Ca^{2+} and Mg^{2+} was measured in the received solution. Nitrate nitrogen analyses were carried out in the Central Laboratory IUNG at Pulawy by the colorimetric method. The content of calcium, potassium and magnesium was determined by using the F-AAS method in the analytical laboratory of Agricultural and Environmental Chemistry Department at the Agriculture University in Lublin. Laboratory experiment results were statistically worked out by analysis of variance double classification method with Tukey's confidence semi ranges. Values of pH were calculated in ad-

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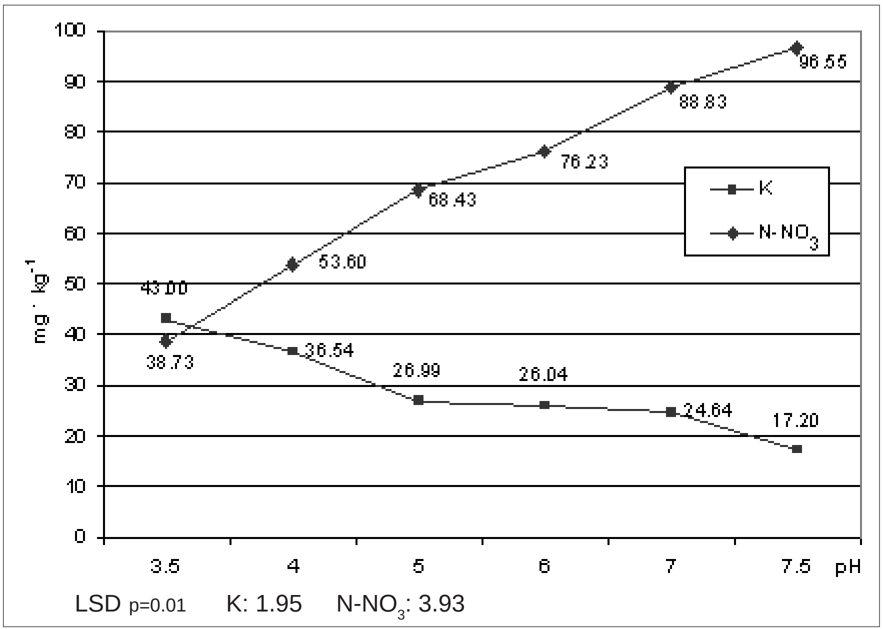

Figure 1: **Average content of nutrients active form (K^+, $N\text{-}NO_3$) in soils of the laboratory experiment.**

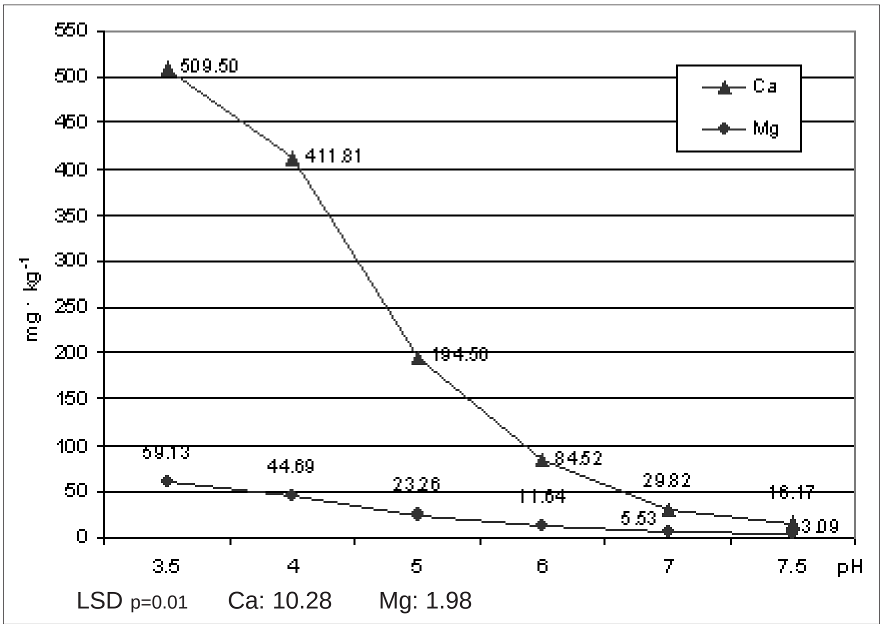

Figure 2: **Average content of nutrients active form (Ca^{2+}, Mg^{2+}) in soils of the laboratory experiment.**

vance to hydrogen ions concentration in the water-soil suspension. The relationships between the hydrogen ions concentration in the water-soil suspension and nutrients active form concentration in soil, were estimated as simple correlation method and linear regression analysis.

Results and Discussion

In the laboratory experiment, the content of the selected nutrients active form was compared between soils with diversified pH. The assumption was that, the nutrient active form is most sensitive on leaching in the case of adequate water flow through the soil profile.

The content of $N\text{-}NO_3$ in the soil was decreased significantly as acidification increased and these values were a few times lower at 3.5 than at pH 7.5. (*Figure 1*.)

It was probably connected with the limitation of nitrification efficiency which is conducted by autotrophic bacteria [HAYNES and SWIFT, 1986; ROBSON and ABBOTT, 1989].

The profiles of potassium, calcium and magnesium active form contained in the soil were behaved very similarly. (*Figure 1, 2*). The maximum contents of K, Ca and Mg were extracted from pH 3.5 treatments, however minimal from pH 7.5 treatments. There is probably mechanics of exchangeable cations (K^+, Ca^{2+} and Mg^{2+}) displacing from sorption complex by H^+ and Al^{3+} ions, which have higher entry energy to sorption complex [HAYNES and SWIFT, 1986; WALNA et al., 1998]. Displaced ions K^+, Ca^{2+} and Mg^{2+} are moved to a soil solution and could be leached in favorable conditions. Reduction of sorption complex capacity due to the acidification has a great importance too. GOULDING and BLAKE [1998b] noticed that over 30% irreparable reduction cation exchangeable capacity (CEC) as an effect of type 2:1 clay minerals weathering in the conditions of progressive acidification. There is a reduction of organic matter sorption capacity due to dissociation of humic acid function groups [HARTIKAINEN, 1996]. The amount of extracted calcium was higher than the amount of magnesium because of the initial content of calcium in soils used in the experiment was probably higher than the content of magnesium.

The strong increase of soil acidification in non-limed treatments as a result of 24 years of intensive NPK fertilization or fallowing was clearly visible in selected results from the lysimeter experiment. (*Table 1*). The fall of pH_{KCl} from 0.6 to 1.1 units and the significant increases of hydrolytic acidity were observed. In the case of fertilized treatments it confirmed acidifying effects after a long time of nitrogen and potassium fertilization [FILIPEK et al., 1999; GOULDING and BLAKE, 1998b], and in the case of fallowed treatments - and the influence of a humid climate (advantage of precipitation over evaporation and base cations leaching down the soil profile) [LÆGREID et al., 1999].

The kind of soil and manner of soil utilization primarily affected the amount of soil leachates. Several times more leachates were found from fallowed soil

Table 1: **Acidification indicators and the content of exchangeable cations in the soils (0 - 30 cm) from start to end of the lysimeter experiment (1977 - 2001).**

Treatment	pH_{KCl}		Hh mmol H^+ . kg^{-1}		K^+		Ca^{2+} mg . kg^{-1}		Mg^{2+}	
	1977	2001	1977	2001	1977	2001	1977	2001	1977	2001
Sandy soil										
NPK + Ca		6.5		14.0		66.47		761.52		53.49
NPK	4.9	3.9	30.8	41.0	140.77	66.86	501.00	180.36	18.23	20.67
Fallow		4.2		31.5		64.50		262.00		9.90
Loess soil										
NPK + Ca		6.5		12.0		117.31		1002.00		93.60
NPK	5.8	4.8	18.8	32.0	199.42	105.58	851.70	561.12	55.92	80.23
Fallow		5.8		16.5		278.33		758.00		78.80
Loamy soil										
NPK + Ca		6.2		14.0		148.59		1062.12		121.56
NPK	5.4	4.8	21.0	32.0	156.41	144.68	1092.18	761.52	89.95	133.72
Fallow		5.3		21.0		115.74		874.46		102.70

Table 2: **Average concentrations of $N\text{-}NO_3$ in the lysimeter experiment [mg . dm^{-3}].**

Years	NPK + Ca	NPK Sandy soil	Fallow	NPK + Ca	Treatment NPK Loess soil	Fallow	NPK + Ca	NPK Loamy soil	Fallow	In rainfall
1991	15.67	21.17	19.80	9.57	4.00	13.50	18.87	14.40	13.80	3.68
1992	56.20	53.80	52.90	-*	-	26.90	16.30	14.50	47.30	2.12
1993	43.50	44.67	46.20	19.57	18.20	57.30	20.40	21.07	64.90	4.48
1994	56.80	49.73	35.50	25.90	25.60	36.10	33.53	34.80	40.50	2.87
1995	39.20	42.97	33.40	22.83	20.43	28.10	27.37	26.27	33.90	3.07
1996	34.10	30.10	32.00	-	20.15	21.50	23.37	18.13	27.10	2.89
1997	33.60	30.70	24.00	23.30	18.90	18.40	25.47	27.90	25.80	2.65
1998	34.83	28.67	16.80	31.03	30.03	18.50	38.77	48.10	21.60	2.20
1999	20.53	19.13	10.20	8.07	8.50	7.90	10.37	12.67	12.60	2.20
2000	9.50	5.97	12.80	6.23	3.03	9.90	5.97	9.03	9.90	1.70
2001	23.57	13.10	17.40	4.00	3.70	11.30	6.20	3.77	11.20	3.74
Mean	33.41	30.91	27.36	16.72	15.26	22.67	20.60	20.97	28.05	2.87

* No water in lysimeters in this year (apply to tables 2 - 5)

Table 3: **Average concentrations of K^+ in the lysimeter experiment [mg . dm^{-3}].**

Years	NPK + Ca	NPK Sandy soil	Fallow	NPK + Ca	Treatment NPK Loess soil	Fallow	NPK + Ca	NPK Loamy soil	Fallow	In rainfall
1991	5.40	6.43	29.70	0.73	0.97	1.40	0.73	0.90	0.60	0.56
1992	11.80	13.20	39.70	-	-	3.00	2.63	2.07	1.70	0.18
1993	17.13	13.90	40.00	1.80	1.93	1.90	1.63	1.80	1.30	0.39
1994	14.83	14.30	51.90	1.97	2.17	1.60	1.17	1.70	1.30	0.38
1995	10.53	9.63	39.30	1.47	1.90	1.10	0.97	1.20	0.70	0.33
1996	8.97	12.30	72.30	-	4.80	1.80	1.33	1.57	1.00	0.43
1997	14.67	19.83	34.00	2.17	2.03	1.50	1.33	1.63	0.80	0.37
1998	8.53	15.80	33.60	0.80	0.77	1.10	0.73	0.80	0.60	0.30
1999	6.97	13.73	25.50	0.70	0.83	1.00	0.83	0.73	0.80	0.30
2000	5.80	12.33	26.30	0.77	0.67	1.10	0.90	0.93	0.90	0.40
2001	11.37	16.13	24.00	0.80	1.13	1.40	1.27	1.30	1.20	0.60
Mean	10.55	13.42	37.85	1.24	1.72	1.54	1.23	1.33	0.99	0.39

rather than the others (*Table 6*). Consequently the greatest nutrient leaching was from fallowed treatments too. It was connected with both low water retention in the soil without plants and the soil structure deterioration as a result of its acidification, which caused increase of water flow down the soil profile. [FILIPEK, 1994; RUSZKOWSKA et al., 1994].

The concentration of investigated nutrients in soil leachates depended on the kind of soil and also the manner of soil utilization. The higher $N\text{-}NO_3$ concentration in leachates from limed treatments compared to non-limed treatmets occurred in the sandy and the loess soils. (*Table 2*). Such significant differences

Table 4: **Average concentrations of Ca^{2+} in the lysimeter experiment [mg . dm^{-3}].**

Years	NPK + Ca	NPK	Fallow	NPK + Ca	NPK	Fallow	NPK + Ca	NPK	Fallow	In rainfall
					Treatment					
		Sandy soil			Loess soil			Loamy soil		
1991	40.27	55.57	139.60	127.10	93.47	62.30	82.23	70.60	74.40	3.28
1992	135.17	132.97	129.90	-	-	94.90	84.30	51.13	94.40	1.67
1993	214.93	189.97	115.20	177.50	115.63	144.60	133.00	129.53	119.90	2.58
1994	113.33	108.10	71.50	190.07	169.97	98.60	90.27	106.75	87.20	1.38
1995	96.40	79.90	52.40	158.47	132.57	63.60	89.20	105.93	70.50	2.95
1996	77.03	58.10	47.90	-	37.15	46.70	74.93	77.30	58.80	1.98
1997	114.20	85.37	37.20	133.13	100.30	48.70	113.27	115.37	59.00	2.25
1998	56.10	42.00	30.20	99.33	67.10	49.50	81.20	107.10	58.00	2.40
1999	56.47	40.67	24.40	50.57	36.33	32.70	58.73	59.40	50.20	4.10
2000	57.70	35.67	30.60	47.97	27.73	32.70	59.47	66.07	56.40	1.80
2001	93.67	58.50	39.60	69.17	55.70	42.30	79.00	92.60	60.70	2.10
Mean	95.93	80.62	65.32	117.03	83.60	65.15	85.96	89.25	71.77	2.41

Table 5: **Average concentrations of Mg^{2+} in the lysimeter experiment [mg . dm^{-3}].**

Years	NPK + Ca	NPK	Fallow	NPK + Ca	NPK	Fallow	NPK + Ca	NPK	Fallow	In rainfall
					Treatment					
		Sandy soil			Loess soil			Loamy soil		
1991	2.53	6.47	9.10	21.63	16.73	10.00	28.67	24.70	25.10	0.17
1992	9.67	14.70	8.00	-	-	16.60	25.90	29.73	32.00	0.17
1993	14.90	22.17	6.20	26.53	18.63	33.40	41.70	38.93	37.60	0.38
1994	11.50	15.17	4.80	35.73	29.63	16.50	32.67	40.90	31.10	0.20
1995	9.80	9.83	3.10	26.73	23.93	11.40	28.70	31.97	23.60	0.19
1996	7.10	7.50	5.20	-	17.50	9.50	25.50	29.43	20.90	0.16
1997	11.77	12.47	3.60	22.30	18.47	8.80	35.97	38.27	22.60	0.21
1998	5.43	5.33	1.90	14.40	10.33	6.80	25.40	33.67	17.30	0.10
1999	5.00	4.43	1.50	6.83	5.33	4.20	16.13	19.53	15.80	0.20
2000	5.43	4.37	2.10	6.37	4.10	4.10	17.73	20.47	16.80	0.10
2001	8.77	7.57	2.10	8.10	7.03	5.00	25.43	29.57	17.60	0.20
Mean	8.35	10.00	4.33	18.74	15.17	11.48	27.62	30.65	23.67	0.19

Table 6: **Average amounts of percolates, percolating nutrients and precipitation for years 1991 - 2001 in the lysimeter experiment.**

Treatment	Percolates	$N\text{-}NO_3$	K	Ca	Mg
	mm		g . m²		
Sandy soil					
NPK + Ca	268	6.72	2.31	19.04	1.76
NPK	343	6.47	5.03	17.89	2.26
Fallow	472	14.18	25.32	31.22	1.96
Loess soil					
NPK + Ca	238	3.17	0.21	18.88	2.65
NPK	242	2.81	0.24	13.56	2.06
Fallow	333	11.17	1.02	35.74	6.88
Loamy soil					
NPK + Ca	292	5.42	0.28	21.62	6.76
NPK	246	4.69	0.24	20.41	6.53
Fallow	413	13.40	0.77	50.10	8.20
In rainfall					
Precipitation	627	2.32	0.36	2.31	0.14

between those treatments did not occur in the loamy soil. Average nitrate nitrogen leaching from limed treatments was higher than from non-limed treatments in all soils. This data can present a partially confirmation of laboratory experiment data as to nitrification intensity reduction in the acid soils. The concentration of nitrate nitrogen in leachates from fallowed treatments was clearly higher than from the cropped ones, both in loess and the loamy soils. It was connected with not only acidification pressure and also accelerated mineralization of soil organic matter that occurs in fallowed soils [RUSZKOWSKA et al., 1994].

The average potassium concentration in soil leachates non-limed treatments was higher in relation to limed treatments in all soils (*Table 3*). In the case of calcium, such tendency concerned the loamy soil only in the case of magnesium - the loamy and the sandy soils. (*Table 3, 4*). The high concentration of calcium in soil leachates, as well as larger leaching from limed treatments; results from calcium deposition with fertilizers used for liming [SUN et al., 2000]. Clear decrease of exchangeable calcium content in non-limed treatments in all soils, only informs us about the influence of acidification on calcium leaching from soils. (*Table 1*). Leaching of potassium from acidifying treatments was clearly higher than from liming treatments only in the sandy soil; however, values from the loess and loamy soils were comparable. The higher magnesium leaching from acidifying treatments was observed only in the sandy soil. The clear influence of acidification on cations leaching from the sandy soil was probably connected with degradation sensitivity of light soils as a result from low sorption complex capacity and low content of organic matter [HARTIKAINEN, 1996].

Conclusions

❶ Soil acidification clearly influences on the nutrients mobility in the laboratory experiment, where it was eliminated or standardized due to the impact of other environmental factors.

❷ Influence of soil acidification on the nutrients mobility is visible in the case of the lysimeter experiment, but there is a powerful affect among other environmental factors such as: the amount of water which flows through the soil profile, mineral fertilization, liming as well as soil covering of plants.

❸ Clear influence of soil acidification on the cations leaching in the lysimeter experiment may be observed only in the sandy soil.

❹ As a result of 24 years of mineral fertilization as well as fallowing, it strongly increases the soil acidification which appeared in non-limed treatments.

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