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THE EFFECT OF Ca, Mg AND K LEACHING FROM SOILS AS AFFECTED BY SOIL KIND AND THEIR UTILIZATION MANNER

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A b s t r a c t. The purpose of the study was to investigate a long-term effect of mineral fertilization (NPK vs. NPK+Ca) and manner of soil utilization (fallow vs. 4-course rotation) on soil properties and leaching of cations in a lysimeter experiment involving a sandy soil, a loess soil, and a loamy soil.

The amount of leached Ca^{2+}, Mg^{2+}, and K^{+} cations depended primarily on soil kind and soil utilization. The losses of calcium and potassium were greatest on the sandy soil, the smallest calcium losses were recorded on the loess soil. About 50-120 kg Ca, 8-40 kg Mg and 2-20 kg K were leached from 1 ha of cultivated soils in a year; 150-250 kg Ca, 15-90 kg Mg, and 5-85 kg K were leached in the same conditions from uncropped fallowed soils.

After 12 years a significant increase of soil acidification, proportional to pH reduction, was recorded in non-limed and fallowed treatments that coincided with the appearance of mobile Al. Mineral fertilization and leaving the soils uncropped caused a significant decrease in the degree of their base saturation (V), mainly with calcium. Those adverse changes in soil properties depended both on soil kind and starting soil pH. Liming effectively counteracted the acidification of soils fertilized with NPK.

K e y w o r d s: mineral fertilization, cations leaching from soils, lysimeter experiment

INTRODUCTION

A lysimeter experiment has been run in the Institute of Soil Science and Plant Cultivation at Puławy since 1977. The experiment is principally aimed at determining the balance of plant nutrients under various soil conditions and at different mineral fertilization levels.

One of the specific issues to be investigated is how the mineral fertilization affects the chemical properties of the soil and the leaching of base cations from different soils and under different ways of their utilization.

The objective of this study is to present that part of the collected data that bears on the losses of calcium, magnesium and potassium through leaching and on the changes in the properties of the tilled layer of a sandy soil, a loamy soil, and a loess soil after 12 years of the experiment.

MATERIAL AND METHODS

The experiment was run in concrete lysimeters 1 m^2 in area and 1.3 m deep. The inside of the lysimeters was coated with an epoxy resin. The lysimeters were filled with three soils: a brown soil developed from sand, a brown soil developed from loess, and a grey-brown soil developed from loam. A natural layout of genetic horizons of those soil was preserved [4].

A four-course crop rotation was used: potato - spring barley - winter rape - winter wheat. That rotation scheme was repeated over the successive years [5].

An experiment design involved NPK, liming and watering levels that warranted high crop yields [5]. In this paper the data from three treatments are presented only: 1) fallowed, non-fertilized soils; 2) and 3) cropped soils fertilized with double NPK rates: non-limed soils (treatment 2) or limed soils every four years according to 0.5-0.75 Hh (treatment 3). Each treatment was replicated three times (exceptionally two times).

In treatments 2 and 3 fertilizer rates per 1 ha were, depending on the crop, 100-200 kg N as ammonium nitrate, 60-100 kg P_2O_5 as granulated superphosphate, and 100-160 kg K_2O as potassium chloride. The soils were fertilized also with 24 kg Mg/ha as magnesium sulphate: the sand soil and the loess soil - every year, and all soils - in the 3rd rotation cycle.

The crops were harvested at full maturity. Soil leachates were weighed once a month, as a rule, or more frequently, as the cans became filled. The pooled water samples were analysed for mineral element contents. Ca and K were measured using flame spectrophotometry, and Mg by the AAS method.

Each year, after crop harvest, representative samples of soils were collected from the depth of 0-30 cm. Every four years the samples from subsoil were also collected. Soil analyses were run using the methods adopted by the Agrochemical Stations [3].

Other relevant details were given in the earlier publications [4,5].

RESULTS

The experiment had a free exposure to atmospheric precipitation (*ca.* 600 mm annually). The amount of soil leachates was related to kind of soil and manner of soil utilization. Three to four times more leachates were collected from non-cultivated soils (fallows) than from the cropped ones (Table 1). Consistently, the fewest leachates were collected from the loess soil. An excessive permeability of the loamy soil can be accounted for by a slow recovery of its initial compact subsoil structure disturbed by filling the lysimeters with soil material in 1977.

The concentration of Ca^{2+}, Mg^{2+}, and K^+ ions in soil leachates depended on kind of soil (Table 1). The concentration of Ca^{2+} ions was always much higher than of the remaining two cations. The leachates from the sandy soil were characterized by a generally higher Ca^{2+} concentration, much higher K^+ concentration and lower Mg^{2+} concentration than the leachates from the two other soils. The leachates recovered from the fallowed sandy and loess soils had substantially lower concentrations of Ca^{2+} and Mg^{2+} ions than those collected from cropped soils. A similar relationship was not observed on the loamy soil, richer in available calcium and magnesium.

Table 1. Precipitation, lysimetric leakages, concentrations and calcium, magnesium and potassium leaching from soil. Mean values of 1978-1989

Soil Treatment	Leakages (dm^3/m^2)	Concentrations (mg/dm^3)			Leaching (g/m^2*)		
		Ca^{2+}	Mg^{2+}	K^+	Ca^{2+}	Mg^{2+}	K^+
Sandy soil							
Fallow	253	84.6	5.8	38.2	20.8	1.4	8.4
NPK	63	229.4	11.9	32.9	11.8	0.8	2.2
NPK+Ca	73	202.8	12.1	31.6	14.8	1.0	2.3
Loess soil							
Fallow	140	101.8	17.6	3.7	14.4	2.5	0.5
NPK	31	156.2	26.7	5.6	4.9	0.8	0.2
NPK+Ca	32	196.5	34.1	5.1	6.5	1.2	0.2
Loamy soil							
Fallow	262	94.7	31.6	1.9	24.4	8.9	0.5
NPK	97	93.6	29.1	2.5	9.5	3.3	0.3
NPK+Ca	95	99.2	30.7	2.6	10.2	3.6	0.3
		Precipitation			Income (g/m^3*)		
	590	6.2	1.0	0.5	3.7	0.6	0.3

**x10=kg/ha/year.

Leaching of calcium was much lower from the loess soil than from the remaining two soils. The least magnesium was leached from the sandy soil, poor in that nutrient and the most - from the loamy soil.

Potassium losses through leaching were the greatest from the sandy soil. Little leaching of K^+ ions occurred in the loess and the loamy soils, having a richer sorption complex. Three investigated elements were leached more intensively from the fallowed soils than from the cropped ones.

Data presented in Table 2 show that the studied soils differ in their granulometric composition which was caused by the geological origin of the parent rocks. Alongside with substantial differences in the content of colloidal fraction (<0.02 mm), that fell with the range of 4 to 12 %, those soils were characterized by different degrees of acidification. Indeed, the starting pH in 1 mol KCl/dm^3 of those soils ranged from 4.9 for the sandy soil to 5.8 for the loamy soil. Those characteristics indicate that the soils in their initial state had different buffering capacities even though their organic C contents were similar, though low.

After 12 years of heavy NPK fertilization or fallowing the studied soils underwent significant acidification that was accompanied by a fall of pH_{KCl} from 0.8 to 1.4 units. In addition, beside the appearance of mobile Al, a rise of potential acidity forms occurred also in the loamy soil and in the loess soil, the soils showing no signs of mobile Al at the beginning of the experiment. Mineral fertilization and leaving the soils uncropped markedly decreased their saturation degree with base cations (V). The greatest decline of the V value occurred in the soil developed from light loamy sand where both NPK fertilization and fallowing brought about a 30 % reduction of that indicator. Liming was effective against the acidification of heavily NPK-fertilized soils. Acidity was more effectively neutralized by liming in the loess soil and in the loamy soil than in the sandy soil.

Long-term NPK fertilization had a reducing effect on the content of exchangeable cations in the soil, mainly that of calcium (Table 3). The same situation occurred in the case of fallowed soils. The greatest losses of exchangeable Ca^{2+} were recorded in treatments with the sandy soil and with the unlimed loess soil. The effect of the studied factors on the content of exchangeable Mg^{2+} and K^+ in soils was less straightforward. The occurrence of those cations was dependent both on the kind of soil and applied fertilization including magnesium treatment. A systematic liming carried out every

Table 2. Properties of arable layer (0-30 cm) of soils after 12 years of experiment

Soil / Treatment	Fractions (%) <0.02	Fractions (%) <0.002	Organic C (%)	pH (KCl)	Hh (mmol(+) $100g^{-1}$)	H exch. (mmol(+) $100g^{-1}$)	Al mobil. (mmol(+) $100g^{-1}$)	V (%)
Sandy soil								
Initial sample (1977)	12	4	0.87	4.9	3.08	0.30	0.20	50
Fallow			0.70	4.1	3.64	0.79	0.49	30
NPK			1.04	3.6	4.43	1.00	0.70	27
NPK+Ca			0.98	5.3	2.48	0.0	0.0	61
Loess soil								
Initial sample (1977)	38	8	0.88	5.8	1.88	0.0	0.0	74
Fallow			0.68	4.9	2.52	0.23	0.12	65
NPK			1.11	4.6	3.63	n.d.	n.d.	54
NPK+Ca			0.98	5.9	1.60	0.0	0.0	82
Loamy soil								
Initial sample (1977)	30	12	0.90	5.4	2.10	0.0	0.0	76
Fallow			0.54	4.3	2.78	0.32	0.16	65
NPK			1.06	4.4	3.28	0.31	0.15	63
NPK+Ca			0.96	6.0	1.55	0.0	0.0	84

n.d. - not determined.

Table 3. The content of exchangeable cations in the soils (0-30 cm) after 12 years of the experiment (1977-1989)

Soil Treatment	Ca^{2+}	Mg^{2+}	K^+	S
	(mmol (+) 100 g^{-1})			
Sandy soil				
Initial sample (1977)	2.50	0.15	0.36	3.07
Fallow	1.25	0.09	0.17	1.54
NPK	1.12	0.15	0.29	1.62
NPK+Ca	3.16	0.35	0.34	3.95
Loess soil				
Initial sample (1977)	4.25	0.46	0.51	5.27
Fallow	3.88	0.42	0.38	4.74
NPK	3.28	0.57	0.43	4.34
NPK+Ca	6.11	0.71	0.41	7.29
Loamy soil				
Initial sample (1977)	5.45	0.74	0.40	6.69
Fallow	4.24	0.48	0.30	5.05
NPK	4.41	0.70	0.43	5.60
NPK+Ca	6.74	0.72	0.49	8.01

four years not only made up for the losses of exchangeable Ca^{2+} but also substantially increased the content of that element in the arable soil layer. It also effectively increased exchangeable magnesium content and, in the sandy and the loamy soils, also raised the content of available potassium (Table 3).

DISCUSSION

The study confirmed the well known fact of mineral fertilization-related acidification of soils [1,4,8]. The essential role in this respect is played by nitrogen fertilizers. Their acidifying effect appears, according to some authors, only at rates 240 or 600 kg N/ha whereas other investigators show that it occurs also at lower rates following long-term application [2,5]. According to Snyder and Champon [8] and Polish investigators [1] the amount of H^+ ions released in the soil as a result of the breakdown of nitrogen fertilizers is related to their form and applied amount whereas the speed of the process depends on the fertilization rate and kind of soil.

The leaching of Ca^{2+}, Mg^{2+}, and K^+ ions, mobile Al-related increase in acidity and the decline of saturation degree of the sorption complex with bases were the consequence of long-term NPK fertilization as shown by the result of this study. The decline reached the critical value in the sandy soil. It means that this soil was heavily degraded by acidification [7]. A long-term fallowing of the soil increased their acidity in a similar manner to mineral fertilization. The results concerning the non-fertilized, fallowed soils also indicate their deterioration that consisted not only in acidification but also in an accelerated humus mineralization [6]. Fallowing as it was shown in a previous studies [6] enhanced the leaching of base cations as consequence of the movement of large amounts of water down the soil profile.

CONCLUSIONS

1. Leaching of Ca^{2+}, Mg^{2+}, and K^+ ions is a complex process and under the conditions of the carried studies was dependent on a number of factors such as granulometric composition and content of mineral elements in soils, amount of precipitation water percolating down the soil profile, presence or absence of vegetation cover, mineral fertilization level, liming, etc.

2. Calcium was the principal base cation leached from the soils. Annual calcium losses were *ca.* 50 to 250 kg Ca/ha, depending on the kind of soil and manner of soil utilization.

3. The sandy soil was threatened with elevated leaching not only of calcium but also of potassium. Leaching of magnesium from that soil led to a substantial decrease of magnesium available forms.

4. The increase in the acidification degree of the soils after 12 years of the duration of the lysimeter experiment was due, among others, to application of mineral fertilizers and to fallowing. The process was characterized by pH reduction, rise of hydrolytic and exchangeable acidity, the appearance of mobile Al and a marked decline of the saturation degree of the sorption complex with bases.

5. Liming effectively counteracted the NPK fertilization-related acidification of soils.

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SKUTKI WYMYWANIA Ca, Mg i K Z GLEBY W ZALEŻNOŚCI OD JEJ RODZAJU I SPOSOBU UŻYTKOWANIA

W doświadczeniu lizymetrycznym z glebą piaskową, lessową i gliniastą badano wieloletni wpływ nawożenia mineralnego (NPK oraz NPK+Ca) i sposobu użytkowania (ugór oraz 4-polowe zmianowanie) na kształtowanie się właściwości tych gleb i straty podstawowych kationów zasadowych przez wymywanie.

Wielkość wymycia jonów Ca^{2+}, Mg^{2+} i K^{+} zależała przede wszystkim od rodzaju gleby i sposobu jej użytkowania. Straty wapnia i potasu były największe z gleby piaskowej, straty wapnia - najmniejsze z gleby lessowej. Z gleb uprawianych ulegało wymyciu w ciągu roku w przeliczeniu na 1 ha około 50-120 kg Ca, 8-40 kg Mg i 2-20 kg K, natomiast z ugorów 150-250 kg Ca, 15-90 kg Mg i 5-85 kg K.

Po 12 latach badań wykazano istotny wzrost zakwaszenia gleb z pojawieniem się glinu ruchomego, w ilościach proporcjonalnych do spadku pH, w obiektach nie wapnowanych oraz w warunkach ugorowania. Nawożenie mineralne oraz pozostawienie gleb bez obsiewu spowodowało wyraźne obniżenie stopnia wysycenia kompleksu sorpcyjnego kationami zasadowymi, głównie wapniem. Te niekorzystne zmiany we właściwościach gleb zależały zarówno od ich rodzaju jak i wyjściowego pH. Wapnowanie skutecznie przeciwdziałało zakwaszaniu się gleb nawożonych NPK.

S ł o w a k l u c z o w e: nawożenie mineralne, wymywanie kationów z gleb, doświadczenie lizymetryczne.