J. Elem. s. 547–557 DOI: 10.5601/jelem.2012.17.4.01

INFLUENCE OF LIQUID MANURE AND NPK ON SELECTED SORPTION PROPERTIES OF SOIL

Wiesław Bednarek[1], Sławomir Dresler[2], Przemysław Tkaczyk[3], Agnieszka Hanaka[2]

[1]Chair of Agricultural and Environmental Chemistry
University of Life Sciences in Lublin
[2]Department of Plant Physiology
Maria Curie-Skłodowska University in Lublin
[3]Regional Chemical-Agricultural Station in Lublin

Abstract

The aim of the experiment was to assess the effect of long-term fertilization with liquid manure applied annually and biennially and with mineral fertilizers on selected sorption properties of soil, i.e. the content of exchangeable magnesium, potassium, calcium, sodium and as well as the value of hydrolytic acidity, sorption capacity and base cation saturation ratio. It was found that fertilization with liquid manure, in contrast to NPK application (N as NH_4NO_3, P as triple super phosphate, K as KCl), led to a significant rise in the content of exchangeable magnesium in soil, whereas application of liquid manure or mineral fertilizers contributed to a significant increase in the potassium content in soil. Application of liquid manure did not cause significant changes in the value of hydrolytic acidity between the lowest and the highest dose used, while mineral fertilization contributed to an increase in the value of hydrolytic acidity. Application of liquid manure reduced the value of hydrolytic acidity as deep as the third layer of the soil profile. Fertilization with liquid manure and mineral fertilizers did not affect the content of exchangeable calcium in the whole soil profile, although the calcium content in the soil profile increased to the 51-75 cm layer. Application of liquid manure and NPK did not alter significantly the content of exchangeable sodium in soil. Upon application of both liquid manure and NPK, no significant changes were observed in the total base exchangeable cations in soil (S) or in the sorption complex saturation (V). However, S and V significantly increased along the depth of sampling. It was found that fertilization with both liquid manure and mineral fertilizers did not induce substantial changes in the soil sorption capacity, although there was an increase in the total sorption capacity in two layers (51-75 cm and 76-100 cm) of the soil profile.

prof. dr hab. Wiesław Bednarek, Chair of Agricultural and Environmental Chemistry, University of Life Sciences, Akademicka 15, 20-033 Lublin, Poland, phone: (081) 4456830, e-mail: wieslaw.bednarek@up.lublin.pl

Key words: liquid manure; natural fertilizers; soil sorption properties; long-term fertilization.

WPŁYW GNOJOWICY I NPK NA WYBRANE WŁAŚCIWOŚCI SORPCYJNE GLEBY

Abstrakt

Celem eksperymentu było określenie wpływu wieloletniego nawożenia gnojowicą, stosowaną co rok i co dwa lata, oraz nawozami mineralnymi na wybrane właściwości sorpcyjne gleby, tj. zawartość wymiennego magnezu, potasu, wapnia, sodu oraz wartość kwasowości hydrolitycznej, pojemność sorpcyjną i stopień wysycenia kationami zasadowymi. Stwierdzono, że nawożenie gnojowicą spowodowało istotne zwiększenie zawartości magnezu wymiennego w glebie w przeciwieństwie do nawożenia NPK (N jako NH_4NO_3; P jako superfosfat potrójny; K jako KCl). Natomiast zarówno nawożenie gnojowicą, jak i nawożenie mineralne przyczyniło się do istotnego przyrostu zawartości potasu w glebie. Nawożenie gnojowicą nie spowodowało istotnych zmian wartości kwasowości hydrolitycznej między najmniejszą a największą zastosowaną dawką, zaś nawożenie nawozami mineralnymi przyczyniło się do wzrostu wartości kwasowości hydrolitycznej. Zastosowanie gnojowicy zmniejszyło wartość kwasowości hydrolitycznej do trzeciego poziomu w profilu glebowym. Nawożenie dawkami gnojowicy i nawozów mineralnych nie spowodowało zmian zawartości wapnia wymiennego w glebie, natomiast zawartość wapnia w profilu glebowym wzrastała do warstwy 51-75 cm. Nawożenie gnojowicą i NPK nie spowodowało istotnych zmian w zawartości sodu wymiennego w glebie. Zarówno po zastosowaniu gnojowicy, jak i NPK nie zaobserwowano istotnych zmian w całkowitej zawartości kationów zasadowych w glebie (S), a także stopnia wysycenia nimi kompleksu sorpcyjnego (V). Natomiast parametry S i V istotnie wzrastały wraz z głębokością pobrania próby. Stwierdzono, że nawożenie zarówno gnojowicą, jak i nawozami mineralnymi nie spowodowało istotnych zmian pojemności sorpcyjnej gleby, ale wykazano przyrost całkowitej pojemności sorpcyjnej w dwóch warstwach profilu gleby, 51-75 cm i 76-100 cm.

Słowa kluczowe: gnojowica, nawożenie mineralne, właściwości sorpcyjne gleby, nawożenie długoletnie.

INTRODUCTION

The 2002 agriculture census showed that farms in Poland produced 31.5 million m^3 of liquid manure, which was equivalent to approximately 23 kg NPK per 1 ha of arable land. It can be assumed that production of this fertilizer will increase as more livestock, especially cattle and swine, is reared. Increasing application of liquid manure may induce specific changes in the natural environment (Mazur, Sądej 1989, Choudhary et al. 1996, Qian et al. 2005, Popers et al. 2011). Therefore, constant monitoring of the impact of the fertilizer on soil, water, plants and air is strongly advisable. Long-term fertilization experiments may provide many interesting and reliable results (Maćkowiak 2000, Potarzycki 2000, Walker, Bernal 2004, Gondek And Filipek-Mazur 2005). Analysis of the impact of a type and dose of fertilizer on selected soil parameters, of which the most important are the grain-size distribution, pH, organic carbon content and sorption capacity, is crucial for optimization of growing conditions and environmental protection (POTARZYCKI 2000).

The aim of the study was to estimate the effect of long-term fertilization with liquid manure and NPK on the sorption properties of soil, an important element of the natural environment.

MATERIAL AND METHODS

The paper is based on results of chemical analyses of soil samples collected in the spring 2002 from an experiment conducted by MAĆKOWIAK (2000) since 1973 and used in this study with the author's consent. The experiment was performed on fenced 1 m^2 plots located in the vicinity of a vegetation hall at the IUNG Institute of Soil Science and Plant Cultivation, Puławy, Poland. The plots were filled with soil to 1 m depth. The soil was taken from an arable field of the IUNG Experimental Station in Grabów, Poland; its grain-size composition corresponded to loamy sand and loam in the subsoil, where the natural layers of the soil profile were preserved. It was only in the 0–25 cm layer that the soil had been mixed in a 2:1 ratio with low-clay humic sandy loam, sampled from the topsoil of an arable field at the Experimental Station of the IUNG in Sadłowice, Poland. The content of available nutrients in the topsoil was: 2.09 mg kg^{-1} P and 6.47 mg kg^{-1} K; the pH_{KCl} was 5.6 and the content of organic carbon equalled 1.06%.

Bovine liquid manure was applied annually at doses of 25, 50, 100 and 200 m^3 ha^{-1} and biennially at double doses. Liquid manure was used in the above doses during the successive seventeen years, i.e. until 1989. On average, the fertilizer contained 9.10% d.m., and 0.31% N, 0.07% P, 0.34% K, 0.16% Ca and 0.03% Mg in fresh weight. In 1990, the application of liquid manure was discontinued and its subsequent effect was investigated until 1999. In order to compare liquid manure and mineral fertilizers, the experiment included four treatments fertilized only with NPK in the form of mineral fertilizers at a dose approximately corresponding to half the dose of each of these components incorporated into soil in the respective treatments where liquid manure was applied annually. The NPK doses were: 50, 100, 200 and 400 kg ha^{-1} N (as NH_4NO_3; 34% N); 10.9; 21.8; 43.6 and 87.2 kg ha^{-1} P (20% P); and 41.5; 83; 166 and 332 kg ha^{-1} K (as KCl; 47.3% K). No liming was applied throughout the whole experiment. The details on the methodology of the experiment can be found in BEDNAREK et al. (2012).

Chemical analyses were performed at the Regional Chemical and Agricultural Station laboratory, Lublin, Poland, with the following methods: exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) after extraction with 1 mol CH_3COONH_4 dm^{-3}, pH 7.0 from the soil and quantitative determination in the filtrate performed with the ASA method; the content of organic carbon was determined according to Tiurin's method; pH was assessed in 1 mol KCl dm^{-3} and hydrolytic acidity was determined by Kappen's method after extraction with 1 mol CH_3COONa dm^{-3} from soil (*Katalogue*... 2007). Statistical analyses were employed such as variance analysis with Tukey's confidence semi-intervals ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Annual application of liquid manure and biennial treatment with double doses did not cause significant changes in the value of hydrolytic acidity between the lowest and highest doses (Table 1). It was found that hydrolytic acidity in the soil profile significantly declined reaching the third layer. Fertilization with NPK resulted in a steady rise in hydrolytic acidity from 10.8 (1 NPK) to 12.8 mmol(+) kg^{-1} (4 NPK), creating a significant difference between the extreme doses. Similarly, POTARZYCKI (2000) reported that 20-year-long application of cattle manure led to an evident decline in exchangeable hydrolytic acidity (60.0 mmol(+) kg^{-1}) in soil compared to treatments fertilized with NPK (70.0 mmol(+) kg^{-1}). In contrast, MAZUR and SĄDEJ (1989) found that a lower dose of swine manure (46.7 t ha^{-1}) raised hydrolytic acidity (Hh) (33.7 mmol(+) kg^{-1}), whereas a higher dose (126.4 t ha^{-1}) failed to induce such a change so that the value of this parameter was the same as in a control, non-fertilized treatment (26.2 mmol(+) kg^{-1}). Elevated hydrolytic acidity was reported by GONDEK and FILIPEK-MAZUR (2005) in their study on mineral, organic and organic-mineral fertilizers.

Application of increasing doses of liquid manure and mineral fertilizers did not produce regular changes in the content of exchangeable calcium in soil (Table 1). However, the Ca^{2+} content in the soil profile increased steadily, particularly as deep as the third 51-75 cm layer. Literature provides discrepant results of studies on the calcium content in soil, i.e. CHOUDCHARY et al. (1996) reported its increase on application of swine manure, while QIAN et al. (2005) found either no changes or a decline in the content of this element. POTARZYCKI (2000) reported a significant increase in the content of exchangeable calcium in the sorption complex of soil fertilized with liquid manure (36.6 mmol(+) kg^{-1} compared to soil supplemented with NPK (11.6 mmol(+) kg^{-1}). Similar regularities were found by MAZUR and SĄDEJ (1989), who reported a substantial increase in the content of exchangeable calcium (57.0 mmol(+) kg^{-1}), particularly when a lower dose of swine manure was applied, compared to the control treatment (44.1 mmol(+) kg^{-1}). Soil properties, e.g. the content of exchangeable K, Mg, and Ca, were also analysed by PYPERS et al. (2011) in their study at the 15 cm topsoil layer.

Table 1

The value of soil hydrolytic acidity and the content of calcium in soil fertilized with liquid manure and NPK

Soil layer (cm)	Liquid manure (m^3 ha^{-1})										NPK (kg ha^{-1})					Mean
	annually					biennially										
	25	50	100	200	mean	50	100	200	400	mean	1	2	3	4	mean	
Hydrolytic acidity [mmol(+) kg^{-1} d.w.]																
0-25	17.8	16.3	20.3	19.4	18.5	15.9	17.7	18.5	22.6	18.7	18.1	18.2	18.4	19.9	18.6	18.6
26-50	11.7	11.1	11.3	10.5	11.1	11.6	11.7	12.8	12.0	12.0	10.7	12.8	14.4	16.6	13.6	12.3
51-75	6.90	6.55	6.61	6.78	6.71	6.48	7.28	7.05	6.30	6.78	7.20	6.48	6.32	6.80	6.71	6.73
76-100	7.27	7.33	7.90	6.68	7.30	7.15	8.07	7.83	6.62	7.42	7.25	6.43	6.75	7.73	7.04	7.25
Mean	10.9	10.3	11.5	10.8	10.9	10.3	11.2	11.5	11.9	11.2	10.8	11.0	11.5	12.8	11.5	11.2
HSD (0.05) (fertilization type – 0.66; (depth×fertilzation type) – 1.87; (fertilization type×fertilization rate) – 4.99; (depth×fertilization type×fertilization rate) – 3.97																
Ca^{2+} [mmol(+) kg^{-1} d.w.]																
0-25	18.5	22.8	23.6	29.9	23.7	19.7	18.5	21.8	25.5	21.4	18.4	16.1	17.0	17.0	17.1	20.7
26-50	26.9	29.2	28.4	37.6	30.5	29.9	26.7	26.4	22.6	26.4	32.0	24.7	25.9	24.0	26.7	27.8
51-75	70.9	73.9	84.8	68.3	74.5	80.4	70.7	87.5	81.7	80.0	81.6	85.1	101.6	97.5	91.4	82.0
76-100	77.8	62.2	65.3	66.0	67.8	77.8	62.7	92.8	76.8	77.5	68.2	83.3	88.6	78.1	79.5	75.0
Mean	48.5	47.0	50.5	50.4	49.1	51.9	44.7	57.1	51.6	51.3	50.0	52.3	58.3	54.1	53.7	51.4
HSD (0.05) (fertilization type) – 6.1; (depth×fertilzation type) – 16.9; (fertilization type×fertilization rate) – 31.6; (depth×fertilization type×fertilization rate) – 41.6																

Annual fertilization with increasing doses of liquid manure resulted in a significant rise in the exchangeable magnesium content, especially between the extreme doses (Table 2). A statistically confirmed increase in the Mg form was also found in the soil profile. Similar relationships were also observed at the biennial application of double doses of liquid manure. These results are in agreement with the ones obtained in the study on swine manure conducted by CHOUDHARY et al. (1996) and in investigations carried out by WALKER et al. (2004) on application of poultry manure, in which an increased content of magnesium was reported. Similarly, POTARZYCKI (2000) found that 20-year-long application of cattle manure, compared to NKP fertilization, produced an increase in the exchangeable magnesium content in the sorption complex. A similar conclusion was drawn by MAZUR and SĄDEJ (1989), who observed a similar tendency during 13-year-long application of swine manure, in contrast to a non-fertilized treatment. Different results were obtained by QIAN et al. (2005), who reported that the Mg^{2+}content in soil remained on the same level or declined in response to manure fertilization. However, application of increasing NPK doses resulted in a gradual fall in the Mg^{2+} content; a reverse phenomenon was observed in the soil profile where the content of this element significantly increased down to the 51-75 cm layer.

Annual treatment with liquid manure and its double doses applied biennially resulted in a steady and significant increase (particularly between the extreme doses) in the exchangeable potassium content (Table 2). The results correspond well with those presented by other authors, who measured a rise in the potassium content in soil after swine manure fertilization (CHOUDHARY et al. 1996, QIAN et al. 2005) and poultry manure application (WALKER et al. 2004). Similarly, POTARZYCKI (2000) reported a certain increase in the K^+ content in the sorption complex of soil fertilized with cattle manure, in comparison to mineral fertilization. In soil fertilized with swine manure, the increase was particularly high at application of a double dose 126.4 t ha^{-1} (MAZUR, SĄDEJ 1989). In the topsoil and the 51-75 and 76-100 cm layers, the K^+ content was significantly higher than in the 26-50 cm layer. Also, mineral fertilization produced a steady and significant increase in the K^+ content, particularly between the extreme doses. The K^+ content in the soil profile was similar to that found at application of liquid manure.

The annual application of liquid manure and biennial use of its double doses as well as NPK treatment did not alter significantly the content of exchangeable sodium in soil (Table 3). However, a steady increase in the content of this form of sodium was found in the soil profile, particularly in the third layer (51-75 cm). The investigations performed by CHOUADHARY et al. (1996) indicated an increased content of sodium in soil treated with swine manure. This was consistent with the results obtained by MAZUR and SĄDEJ (1989), who reported the sodium content of 1.4 mmol(+) kg^{-1} in soil fertilized

Table 2

The content of magnesium and potassium in soil fertilized with liquid manure and NPK

Soil layer (cm)	Liquid manure ($m^3 ha^{-1}$)										NPK ($kg ha^{-1}$)					Mean
	annually					biennially										
	25	50	100	200	mean	50	100	200	400	mean	1	2	3	4	mean	
Mg^{2+} [mmol(+) kg^{-1} d.w.]																
0-25	1.23	1.65	1.78	3.02	1.92	1.30	1.23	1.58	2.02	1.53	1.85	2.23	2.33	3.09	2.37	1.94
26-50	2.95	3.46	5.01	6.93	4.59	3.09	3.05	3.91	4.15	3.55	3.67	3.36	3.53	4.94	3.87	4.00
51-75	8.09	8.50	9.57	10.5	9.15	8.13	7.99	8.45	10.3	8.81	8.54	8.26	7.85	6.10	7.69	8.55
76-100	9.02	7.65	9.84	9.12	8.91	9.36	7.95	8.19	8.78	8.57	9.43	9.87	9.02	7.58	8.97	8.82
Mean	5.32	5.31	6.55	7.39	6.14	5.47	5.06	5.63	6.31	5.62	5.87	5.93	5.68	5.43	5.73	5.83
HSD (0.05) (fertilization type – 0.37; (depth×fertilzation type) – 1.04; (fertilization type×fertilization rate) – 3.02; (depth×fertilization type×fertilization rate) – 1.77																
K^+ [mmol(+) kg^{-1} d.w.]																
0-25	1.73	1.98	2.15	3.18	2.26	1.84	1.82	2.18	2.89	2.19	1.61	1.89	1.87	2.80	2.04	2.16
26-50	1.11	1.31	1.87	2.72	1.75	1.03	1.14	1.91	2.36	1.61	0.96	1.01	1.39	1.74	1.27	1.54
51-75	2.30	2.41	3.10	6.17	3.46	2.01	2.20	3.13	7.12	3.62	2.00	2.27	2.41	3.04	2.43	3.18
76-100	2.32	2.30	2.56	4.00	2.79	2.21	2.05	2.28	5.82	3.09	2.24	2.42	2.47	2.23	2.34	2.74
Mean	1.87	2.00	2.42	4.01	2.58	1.78	1.80	2.38	4.55	2.62	1.70	1.90	2.03	2.45	2.02	2.41
HSD (0.05) (fertilization type) – 0.24; (depth×fertilzation type) – 0.99; (fertilization type×fertilization rate) – 0.84; (depth×fertilization type×fertilization rate) – 0.73																

Table 3

The content of sodium and total base exchangeable cations (S) in soil fertilized with liquid manure and NPK

Soil layer (cm)	Liquid manure (m^3 ha^{-1})										NPK (kg ha^{-1})					Mean
	annually					biennially										
	25	50	100	200	mean	50	100	200	400	mean	1	2	3	4	mean	
Na^+ [mmol(+) kg^{-1} d.w.]																
0-25	0.80	0.96	1.05	1.35	1.04	0.80	0.78	0.92	1.15	0.91	0.78	0.67	0.63	0.71	0.70	0.88
26-50	1.09	1.12	1.24	1.51	1.24	1.16	1.04	1.19	1.16	1.13	1.12	0.95	0.91	0.86	0.96	1.11
51-75	2.57	2.59	3.09	2.59	2.71	2.95	2.58	3.29	3.02	2.96	2.67	2.77	3.45	3.14	3.00	2.89
76-100	2.81	2.21	2.63	2.53	2.54	2.87	2.37	3.41	2.67	2.83	2.29	2.93	3.01	2.71	2.74	2.70
Mean	1.82	1.72	2.00	1.99	1.88	1.95	1.69	2.20	1.99	1.96	1.72	1.83	2.00	1.85	1.85	1.90
HSD (0.05) (fertilization type) – 0.19; (depth×fertilzation type) – 0.54; (fertilization type×fertilization rate) – 1.03; (depth×fertilization type×fertilization rate) –1.31																
Total alkaline exchangeable cations (S) [mmol(+) kg^{-1} d.w.]																
0-25	22.2	27.4	28.6	37.4	28.9	23.7	22.4	26.5	31.6	26.0	22.6	20.8	21.9	23.6	22.2	25.7
26-50	32.0	35.0	36.6	48.7	38.1	35.2	31.9	33.4	30.3	32.7	37.8	30.0	31.7	31.6	32.8	34.5
51-75	83.8	87.4	100.6	87.5	89.8	93.5	83.5	102.8	102.1	95.5	94.8	98.4	115.3	109.8	104.6	96.6
76-100	92.0	74.4	80.3	81.6	82.1	92.2	75.1	106.7	94.0	92.0	82.2	98.5	103.1	90.6	93.6	89.2
Mean	57.5	56.1	61.5	63.8	59.7	61.2	53.2	67.3	64.5	61.6	59.4	61.9	68.0	63.9	63.3	61.5
HSD (0.05) (fertilization type) – 6.41; (depth×fertilzation type) – 17.83; (fertilization type×fertilization rate) – 35.58; (depth×fertilization type×fertilization rate) – 43.77																

Table 4

Sorption capacity (T) and base cation saturation ratio (V) in soil fertilized with liquid manure and NPK

Soil layer (cm)	Liquid manure ($m^3 ha^{-1}$)										NPK ($kg ha^{-1}$)					Mean
	annually					biennially										
	25	50	100	200	mean	50	100	200	400	mean	1	2	3	4	mean	
Sorption capacity (T) [mmol(+) kg^{-1}]																
0-25	40.0	43.7	48.9	56.8	47.4	39.6	40.1	45.0	54.2	44.7	40.7	39.0	40.2	43.5	40.8	44.3
26-50	43.7	46.2	47.8	59.3	49.2	46.8	43.6	46.1	42.3	44.7	48.4	42.8	46.1	48.2	46.4	46.8
51-75	90.7	94.0	107.2	94.3	96.6	100.0	90.7	109.8	108.4	102.2	102.0	104.9	121.7	116.6	111.3	103.4
76-100	99.2	81.7	88.2	88.3	89.4	99.4	83.2	114.5	100.6	99.4	89.4	104.9	109.8	98.3	100.6	96.5
Mean	68.4	66.4	73.0	74.7	70.7	71.5	64.4	78.9	76.4	72.8	70.1	72.9	79.5	76.7	74.8	72.8
HSD (0.05) (fertilization type) – 6.13; (depth×fertilization type) – 17.19; (fertilization type×fertilization rate) – 31.58; (depth×fertilization type×fertilization rate) – 41.91																
The degree of saturation with alkaline cations (V) [%]																
0-25	50.8	56.4	53.1	58.0	54.6	54.2	50.9	53.4	52.3	52.7	50.2	47.3	48.6	47.0	48.3	51.9
26-50	65.6	67.1	65.0	67.7	66.4	67.1	65.4	62.8	60.6	64.0	69.5	62.5	60.8	56.7	62.4	64.2
51-75	80.2	81.1	81.8	76.9	80.0	82.4	80.6	81.1	78.6	80.7	81.5	83.1	84.4	84.5	83.4	81.4
76-100	79.6	79.2	77.7	78.4	78.7	80.3	78.0	80.2	78.4	79.2	78.9	81.6	82.0	81.1	80.9	79.6
Mean	69.1	71.0	69.4	70.3	69.9	71.0	68.7	69.4	67.5	69.2	70.0	68.6	69.0	67.3	68.8	69.3
HSD (0.05) (fertilization type) – 1.55; (depth×fertilization type) – 5.18; (fertilization type×fertilization rate) –12.48; (depth×fertilization type×fertilization rate) – 9.26																

with a lower dose of swine manure and 1.6 mmol(+) kg^{-1} with a higher dose, compared to 1.3 mmol(+) kg^{-1} in the control treatment. In contrast, POTARZYCKI (2000) did not find such a tendency: the Na^{+} content in soil fertilized only with cattle manure and with NPK was identical (0.5 mmol(+) kg^{-1}).

Fertilization with liquid manure caused a slight increase in the sorption capacity in the topsoil (Table 4). Additionally, a steady increase in the total sorption capacity in the soil profile was found, especially in the 26-50 cm and above all in the 51-75 cm layers. POTARZYCKI (2000) reported that the total sorption capacity in soil fertilized with cattle manure for 20 years was 101.3 mmol(+) kg^{-1}, compared to just 85.3 mmol(+) kg^{-1} in response to fertilization with NPK. MAZUR and SĄDEJ (1989) found that the total sorption capacity in soil fertilized with a lower dose of swine manure was 105.7, with a higher dose – 90.2, and in non-fertilized soil (control treatment) – only 78.2 mmol(+) kg^{-1}.

Annual application of increasing manure doses, biennial treatment with double doses, and use of mineral fertilizers did not cause pronounced changes in the percentage of base cations (V) in the total sorption capacity (Table 4). In contrast, there was a significant increase in the value of S in the 26-50 and 51-75 cm layers of the soil profile, compared to the topsoil (0-25 cm). In his studies, POTARZYCKI (2000) found that the contribution of S to the total sorption capacity was 41%, and only 18% in soil fertilized with NPK. Similarly, MAZUR and SĄDEJ (1989) found an increase in the share of base cations in the total sorption capacity in soil treated with a lower (68.1%) and higher dose of swine manure (approximately 71%), in comparison to the control, non-fertilized treatment (66.5%).

The values of S, T, and V increased to the third layer, whereas the Hh value declined gradually. The increase in the content of exchangeable cations in the deeper layers of the soil profile was primarily caused by some leaching of individual cations, which were not taken up by crops and did not undergo exchangeable sorption. Another reason was that clay, present on the surface of the examined soil, has a higher sorption potential than sand.

CONCLUSIONS

1. Annual application of increasing doses of cattle manure resulted in a steady increase in the content of Mg^{2+}, K^{+}, Ca^{2+}, Na^{+}, S, and T and an irregular increase in the H^{+} and V content in the arable layer (0-25 cm) and, to a lesser extent, in the other layers of soil.

2. Biennial fertilization with double liquid manure doses led to an increase in the content of Mg^{2+}, K^{+}, H^{+}, Ca^{2+}, Na^{+}, S, and T in the 0-25 cm layer (and in the other soil layers). The degree of saturation of the soil with base cations remained on a relatively stable level of 50.9-54.2%, irrespective of the dose of the fertilizer used.

3. Application of increasing doses of mineral (NPK) resulted in an increase in the content of Mg^{2+}, K^+, H^+, S, and T in the 0-25 cm layer and, to a lesser extent, in the other soil layers, but it did not considerably affect the Ca^{2+} and Na^+ content, although it lowered the V value.

4. Annual application of increasing doses of cattle manure and biennial use of its double doses as well as the NPK treatment increased the content of Mg^{2+}, Ca^{2+}, Na^+, S, T, and V in the soil profile and decreased the content of H^+ ions in the 51-75 cm layer.

REFERENCES

Bednarek W., Dresler S., Tkaczyk P., Hanaka A. 2012. *Available forms of nutrients in soil fertilized with liquid manure and NPK.* J. Elem. (in press).

Catalogue of agrichemical research methods in agri-chemical stations 2007. OSCH-R Lublin, 1-19. (in Polish)

Choudhary M., Bailey L.D., Grant C.A. 1996. *Review of the use of swine manure in crop production: Effects on yield and composition and on soil and water quality.* Waste Manage. Res., 14(6): 581-595.

Gondek K., Filipek-Mazur B. 2005. *The effects of mineral treatment and the amendments by organic and organomineral fertilisers on the crop yield, plant nutrient status and soil properties.* Plant Soil Environ., 51(1): 34-45.

Gondek K., Kopeć M. 2008. *Effect of fertilization on leaching of plant nutrients in a pot experiment.* Acta Agroph., 12(1): 79-89. (in Polish)

Maćkowiak C. 2000. *Comparison of the fertilizng effect of liquid manure and mineral fertilizers.* Nawozy i Nawożenie, 4: 110-118. (in Polish)

Mazur T., Sądej W. 1989. *Effect of long-term fertilization with liquid manure, FYM and NPK on some chemical and physicochemical properties of soil.* Rocz. Glebozn., 40 (1): 147-153.

Potarzycki J. 2000. *Chemical properties of soils after twenty-year-long fertilization with cattle slurry and NPK.* Fol. Univ. Agric. Stetin. 211, Agricultura, 84: 405-410. (in Polish)

Pypers P., Sanginga J.-M., Kasereka B., Walangululu M., Vanlauwe B. 2011. *Increased productivity through integrated soil fertility management in cassava-legume intercropping systems in the highlands of Sud-Kivu, DR Congo.* Field Crops Res., 120: 76-85.

Qian P., Schoenau J.J., King T., Japp M. 2005. *Effect of repeated manure application on potassium, calcium and magnesium in soil and cereal crops in Saskatchewan.* Can. J. Soil Sci., 85: 397-403.

Walker D.J., Bernal M.P. 2004. *Plant mineral nutrition and growth in a saline Mediterranean soil amended with organic wastes.* Commun. Soil Sci. Plant Anal., 35(17-18): 2495--2514.