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ORIGINAL PAPERS

AVAILABLE FORMS OF NUTRIENTS IN SOIL FERTILIZED WITH LIQUID MANURE AND NPK

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Abstract

The aim of the experiment, conducted from 1973 to 1999, was to determine the effect of long-term fertilization with liquid manure (annual and biennial) and with mineral fertilizers on selected physicochemical and chemical properties of soil, i.e., the content of phosphorus, potassium, magnesium, sulphate sulphur, iron, manganese, pH_{KCl} and organic carbon. Fertilization with liquid manure was observed to have resulted in a significant reduction in the content of soil-available phosphorus in comparison to fertilization with NPK. Fertilization with both liquid manure and NPK led to a significant increase in the content of available potassium and magnesium in the soil profile. The highest amounts of $S\text{-}SO_4$ were reported from the topsoil layer, irrespective of the type of fertilizer applied. Fertilization with liquid manure and NPK caused an irregular rise in the content of iron soluble in 1 M HCl in the soil, whereas the content of manganese increased slightly and irregularly in response to the fertilization applied. A negligible rise in pH_{KCl} of the topsoil layer was observed at annual application of increasing doses of liquid manure. It was reported that fertilization with liquid manure led to a steady rise in the organic carbon content in the soil profile.

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

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PRZYSWAJALNE FORMY SKŁADNIKÓW POKARMOWYCH W GLEBIE NAWOŻONEJ GNOJOWICĄ I NPK

Abstrakt

Celem eksperymentu prowadzonego w latach 1973-1999 było określenie wpływu wieloletniego nawożenia gnojowicą, co rok i co dwa lata, oraz nawozami mineralnymi na wybrane właściwości fizykochemiczne i chemiczne gleby, tj. zawartość fosforu, potasu, magnezu, siarki siarczanowej, żelaza, manganu, pH_{KCl} i węgla organicznego. Stwierdzono, że nawożenie gnojowicą, szczególnie stosowaną co rok, spowodowało istotne zmniejszenie zawartości fosforu przyswajalnego w glebie, w porównaniu z nawożeniem NPK. Natomiast zastosowanie nawożenia gnojowicą, a także nawożenia mineralnego, przyczyniło się do istotnego przyrostu zawartości potasu, o największej koncentracji K w dwóch najgłębszych badanych warstwach. Zastosowanie zarówno nawożenia gnojowicą, jak i NPK przyczyniło się do istotnego przyrostu zawartości magnezu przyswajalnego w profilu glebowym, szczególnie w dwóch (NPK) lub trzech (gnojowica) warstwach. Stosunkowo najwięcej $S\text{-}SO_4$ było w warstwie ornej, niezależnie od rodzaju nawożenia. Nawożenie gnojowicą i NPK spowodowało nieregularny przyrost zawartości żelaza rozpuszczalnego w 1 mol HCl w glebie, począwszy od warstwy 26-50 cm, zaś zawartość manganu przyrastała nieznacznie i nieregularnie pod wpływem zastosowanego nawożenia. Zaobserwowano nieznaczny wzrost pH_{KCl} warstwy ornej gleby pod wpływem corocznego stosowania wzrastających dawek gnojowicy. Stwierdzono, że nawożenie gnojowicą spowodowało systematyczne zwiększenie zawartości węgla organicznego w profilu glebowym, szczególnie w dwóch warstwach: 0-25 cm i 26-50 cm.

Słowa kluczowe: gnojowica, nawożenie naturalne, właściwości gleby, długoletnie nawożenie.

INTRODUCTION

Liquid manure is a natural fertilizer composed of faeces and urine of livestock, usually with addition of a small amount of water. It is produced in litter-free breeding houses. Its fertilizing value and chemical composition depend on the animal species and age, feeding system, direction of use and production of animals, dilution with water and the storage system (Borowiec 1986, Maćkowiak 2000, Mazur et al. 1998, Murzyński 1998, Potarzycki 2000). An annual dose of liquid manure (and other fertilizers) should not exceed the amount corresponding to 170 kg ha^{-1} N. Fertilization with liquid manure should ensure optimal use of components that would be adjusted to nutrient demands of plants in order to prevent contamination of the environment, particularly with nitrogen and phosphorus. The best results are obtained by application of liquid manure and mineral fertilizers in combination (Borowiec, Magierski 1980/1981, Mazur, Sądej 2002, Mazur et al. 1998). Locally, fertilization with liquid manure may pose certain problems related to its effect on the environment; therefore, it is essential to recognise the influence of this important element of the environment on soil properties on the basis of long-term experiments (Maćkowiak 2000, Murzyński 1998).

The aim of the study was to determine the effect of long-term fertilization with liquid manure and mineral fertilizers on some physicochemical and chemical soil properties.

MATERIAL AND METHODS

The present report is based on the results of chemical analyses of soil samples obtained in the experiment conducted by MAĆKOWIAK (2000) in spring 2002 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 the level of 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. In the 0-25 cm layer only, the soil was mixed with low clay, humic, sandy loam (the 2:1 ratio) sampled from the topsoil of an arable field at the Experimental Station of the IUNG in Sadłowice, Poland. The concentrations of the available components in the topsoil were 2.09 mg kg^{-1} P and 6.47 mg kg^{-1} K; pH_{KCl} – 5.6; the content of humus was 1.06%.

Liquid cattle manure was applied annually at the doses of 25, 50, 100 and 200 m^3 ha^{-1} and biennially at double doses. Liquid manure in the above doses was applied in 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 1995, 31.4 kg ha^{-1} of phosphorus fertilizers were applied to the treatments with 25, 50 and 100 m^3 doses of liquid manure. Also, all the treatments with liquid manure were supplemented with 99.6 kg ha^{-1} of potassium fertilizers. In 1998 and 1999, mineral fertilization was applied in the whole experiment at equal doses of 120 kg ha^{-1} N, 31.4 kg ha^{-1} P and 99.6 kg ha^{-1} K.

In order to compare the liquid manure and mineral fertilizers, the experiment included only four treatments fertilized with NPK in the form of mineral fertilizers at a dose approximately corresponding to half the dose of each of these components introduced into the soil in the respective treatments where liquid manure was applied annually. The doses were: 50, 100, 200 and 400 kg ha^{-1} N; 10.9; 21.8; 43.6 and 87.2 kg ha^{-1} P; and 41.5; 83; 166 and 332 kg ha^{-1} K. Nitrogen was applied as ammonium nitrate, phosphorus as granular single superphosphate, and potassium as 60% potassium salt. In 1973-1989, the 1NPK treatment was supplemented with 850 kg N, 185.3 kg P and 705.5 kg K, which was equivalent to the dose of 25 m^3 ha^{-1}

of liquid manure. In 1987, the designed nitrogen and potassium doses were reduced by 50% in treatments 3NPK and 4NPK, and the phosphorus dose was decreased by 50% in the 4NPK treatment. In the two successive years, the original nitrogen and phosphorus doses in treatment 3NPK were reduced by 25% and the dose of potassium by 50%; in treatment 4NPK, the doses of nitrogen and phosphorus were lowered by 50%, and that of potassium by 70%. This change was necessitated by the lower crop yield resulting from poorer germination rates and plant density per unit area. Signs of potassium and, to a lesser extent, phosphorus excess were observed on the growing plants. Mineral fertilizers in the re-adjusted doses were applied throughout the experimental period until 1999. In 1990 and 1991, the doses were as follows: N – 50, 100, 150 and 200 kg ha^{-1}; P – 10.9; 21.8; 32.7 and 43.6 kg; and K – 41.5; 62.3; 83 and 103.8 kg ha^{-1}. In 1993-1994 and in 1997, the application of phosphorus and potassium fertilizers was discontinued due to the observed symptoms of excess of the two elements.

The chemical analyses were performed in an accredited laboratory at the Regional Chemical and Agricultural Station, Lublin, Poland, with the following methods: available P and K – with Egner-Riehm method; available Mg – according to Schatschabel method after extraction of 0.0125 mol dm^{-3} $CaCl_2$ from the soil; the content of humus – according to Tiurin method; Fe and Mn soluble in 1 M HCl dm^{-3} – with the ASA method; S-SO_4 – with the nephelometric method according to Bardsley-Lancaster; and pH was assessed in 1 mol KCl dm^{-3} (*A catalogue of methods*... 2007). Statistical analyses were employed such as variance analysis with Tukey's confidence semi-intervals (α=0.05).

RESULTS AND DISCUSSION

The pH_{KCl} of the topsoil layer (0-25 cm) increased slightly in response to the annual application of increasing doses of liquid manure from 5.2 (25 m^3 ha^{-1}) to 5.7 (200 m^3 ha^{-1}) – Table 1. This increase was more pronounced in the deeper soil layers, particularly at 26-50 and 51-75 cm. The biennial application of double doses of this fertilizer did not change the pH of the topsoil, which remained at the level 5.4-5.5. In deeper layers, particularly at 51-75 and 76-100 cm, there was a remarkable increase in pH. Application of liquid manure changed the soil reaction from acid (0-25 cm) to slightly acid (26-50 cm) and neutral in the deeper layers (or even alkaline in the 51--75 cm layer of the soil fertilized biennially with liquid manure). Application of increasing NPK doses contributed to slight acidification of the soil, particularly in the 0-25 and 26-50 cm layers (Table 1). Irrespective of the type of fertilization – organic or mineral – an increase in the pH_{KCl} in the soil profile was reported, which was particularly evident to the depth of 51-75 cm.

It was apparently caused by leaching of alkaline compounds (mainly calcium and magnesium), primarily from the 0-25 cm layer. Borowiec (1986) observed an increase in pH in the successive layers of the soil profile induced by increasing doses of liquid manure as well as by mineral fertilization. Potarzycki (2000) and Mazur et al. (1998) found a slight rise in pH_{KCl} caused by increasing doses of liquid manure; a similar finding was reported by Murzyński (1998). An increase in pH resulting from manure application was also found by Candemira and Glsera (2011), whereas Silva et al. (2009) showed a pH increase upon application of liquid dairy manure and a fall in pH following mineral fertilization.

It was found that fertilization (annual and biennial) with liquid manure led to a steady increase in the content of organic carbon in the soil profile, particularly in the 0-25 cm layer, and a slightly smaller rise in the 26-50 cm layer (Table 1). Mineral fertilization did not act as clearly as liquid manure, but also in this case the highest $C_{org.}$ content was observed in the two top layers of the soil (0-25 and 26-50 cm; Table 1). A similar phenomenon was reported in other investigations (Borowiec 1986, Mazur, Sądej 2002, Mazur et al. 1998, Murzyński 1998, Potarzycki 2000). The decline in the content of organic C after 20 years of the NPK treatment amounted to approximately 10%, whereas the increase in the organic C concentration after 20 years of the application of cattle manure at the rate of 320 Mg ha^{-1} y^{-1} reached 30% (Aoyama, Kumakura 2001). The soil total organic carbon measured in black soil by Han et al. (2006) decreased by 6.5% over 18 years in control and by 5.6% in recycled organic manure treatment.

The annual and biennial fertilization with liquid manure and mineral compounds resulted in a significant increase in the content of available phosphorus, predominantly in the 0-25 and 26-50 cm layers (Table 2). It was found that fertilization with liquid manure, particularly applied every year, produced a significant decline in the phosphorus content in the soil profile; a reverse phenomenon was observed as a result of the NPK fertilization (particularly at the depth of 26-100 cm). In long-term fertilization with liquid manure and chemical fertilizers, the content of available P increased in the 0 to 20 cm soil layer (Yanga et al. 2011). Application of high doses of liquid manure, particularly to acid and light soils, did not prove to contribute to the transfer (leaching) of phosphorus down into the soil profile. Ssimilar observations were reported by Borowiec (1986), Murzyński (1998) and Potarzycki (2000). The study of Ebeling et al. (2003) concerning the impact of various sources of phosphorus on its availability in soil demonstrated that P availability changed depending on the type of organic-mineral fertilization applied.

Application of increasing doses of liquid manure and NPK resulted in a significant rise in the content of available potassium (Table 2). Simultaneously, regardless of the type of the fertilization used – organic or mineral - the highest K concentration was observed in the 51-75 cm soil layer, being

Table 1

Soil pHKCl and the content of organic carbon in soil upon fertilization 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	x	50	100	200	400	x	1	2	3	4	x	
pH_{KCl}																
0-25	5.2	5.6	5.4	5.7	5.5	5.5	5.4	5.5	5.4	5.4	5.4	5.2	5.2	5.1	5.2	5.4
26-50	5.3	5.8	5.9	6.5	5.9	5.5	5.7	5.5	5.7	5.6	5.5	5.4	5.2	5.1	5.3	5.6
51-75	6.7	7.0	7.5	7.3	7.1	7.2	7.2	7.2	7.4	7.3	6.6	7.2	7.1	7.2	7.0	7.1
76-100	6.7	6.4	6.6	7.1	6.7	6.9	6.6	6.8	6.9	6.8	6.5	6.8	6.9	6.7	6.7	6.7
Mean	6.0	6.2	6.3	6.6	6.3	6.3	6.2	6.3	6.4	6.3	6.0	6.1	6.1	6.0	6.1	6.2
HSD (0.05) (fertilization type) – 0.3; (depth×fertilzation type) – 0.6; (fertilization type×fertilization rate) – 1.2; (depth×fertilization type×fertilization rate) – 1.7																
C (%)																
0-25	0.48	0.55	0.81	1.02	0.71	0.55	0.59	0.58	0.89	0.65	0.47	0.44	0.51	0.49	0.48	0.61
26-50	0.19	0.21	0.25	0.36	0.25	0.27	0.20	0.22	0.30	0.25	0.24	0.20	0.23	0.21	0.22	0.24
51-75	0.09	0.07	0.11	0.11	0.10	0.06	0.07	0.07	0.09	0.07	0.10	0.12	0.07	0.10	0.10	0.09
76-100	0.09	0.09	0.13	0.14	0.11	0.05	0.05	0.09	0.13	0.08	0.10	0.09	0.08	0.10	0.09	0.10
Mean	0.21	0.23	0.33	0.41	0.29	0.23	0.23	0.24	0.35	0.26	0.23	0.21	0.22	0.23	0.22	0.26
HSD (0.05) (fertilization type) – 0.03; (depth×fertilzation type) – 0.10; (fertilisation type×fertilization rate) – 0.15; (depth×fertilization type×fertilization rate) – 0.20																

Table 2

The content of available phosphorus and potassium in the soil upon fertilization 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	x	50	100	200	400	x	1	2	3	4	x	
mg P (kg^{-1} d.m.)																
0-25	2.36	2.88	3.65	7.88	4.19	2.27	2.73	3.45	6.65	3.77	2.24	3.08	4.19	6.55	4.01	3.99
26-50	1.56	1.76	2.09	4.57	2.49	1.13	1.51	1.93	3.46	2.01	1.41	1.88	1.98	2.27	1.88	2.13
51-75	1.86	2.15	2.63	2.41	2.27	2.17	2.21	2.09	2.50	2.24	1.73	2.82	2.62	2.81	2.49	2.33
76-100	2.31	1.60	1.59	2.02	1.88	1.66	1.69	2.47	2.37	2.05	4.93	2.50	2.47	2.55	3.11	2.35
Mean	2.02	2.10	2.49	4.22	2.71	1.81	2.04	2.49	3.75	2.52	2.58	2.57	2.81	3.54	2.88	2.70
HSD (0.05) (fertilization type) – 0.63; (depth×fertilzation type) – 2.01; (fertilisation type×fertilization rate) – 2.08; (depth×fertilization type×fertilization rate) – 3.70																
mg K (kg^{-1} d.m.)																
0-25	7.11	7.59	8.11	11.9		8.19	7.64	8.94	10.30		6.72	7.94	7.28	11.0	8.22	
26-50	4.79	5.73	8.39	14.2	8.28	5.09	5.62	8.03			4.62	4.70	6.36		5.82	
51-75	9.96	10.70	19.20	29.3	17.30	13.00	15.10	15.50	34.90	19.60	9.22	11.6	12.2	15.9	12.2	16.4
76-100	10.30	8.22	9.77	17.8	11.50	8.11	10.10	10.40	25.90	13.60	9.77	10.2	13.2	10.4	10.9	12.0
Mean	8.03	8.06	11.40	18.3	11.40	8.60	9.61	10.70	20.20	12.30	7.58	8.61	9.76	11.2	9.29	11.0
HSD (0.05) (fertilization type) – 1.92; (depth×fertilzation type) – 7.04; (fertilisation type×fertilization rate) – 7.14; (depth×fertilization type×fertilization rate) – 8.99																

slightly lower in the 76-100 cm layer, which implies relatively easy leaching of this element from the topsoil, particularly in light and acid soils. Such behaviour of K was not clearly confirmed by Borowiec (1986) or Murzyński (1998), who claim that the content of available potassium forms in soil of the control plot and in the plot that had been steadily fertilized with liquid manure for 20 years did not differ significantly, and that the content was the highest in the 0-20 cm layer.

Annual or biennial fertilization with liquid manure as well as mineral fertilizer application contributed to a significant rise in the content of available magnesium in the soil profile, particularly in two (NPK) or three (liquid manure) layers (Table 3). This implies that Mg easily travels downward through this soil profile. In his study, Borowiec (1986) did not observe this phenomenon, and Murzyński (1998) reported that the highest increase in the content of available magnesium occurred in the 0-20 cm layer. The treatment with liquid dairy manure led to an increase in exchangeable Mg^{2+} levels to the depth of 30 cm, but the mineral fertilizer caused an increase from 30 cm downwards (Silva et al. 2009).

The impact of fertilization with liquid manure and NPK on the content of sulphate sulphur in soil does not demonstrate such a clear tendency as in the case of the elements discussed above (Table 3). The topsoil layer contained the highest amounts of this S form, whose concentration tended to rise as this element leached into the deeper soil profile levels.

Application of liquid manure and mineral fertilizers also resulted in an increase (although irregular) in the content of iron soluble in 1 M HCl in soil (Table 4). A significant increase in the amount of this element was observed in the profile from the 26-50 cm layer downwards. Ye et al. (2006) showed that Fe availability might be increased by allowing manure to decompose in soil.

The content of manganese soluble in 1 M HCl in the soil profile increased slightly and irregularly as a result of the fertilization used (Table 4). The highest content of this element was observed in the topsoil layer. A similar regularity was reported by Murzyński (1998), who found the highest content of this Mn form in the 0-10, 10-20 and 20-30 cm layers, as well as Mazur et al. (1998), particularly upon application of liquid cattle manure. Borowiec and Magierski (1980/1981), however, did not observe such dependencies in light soils fertilized with liquid manure.

Selected chemical or physicochemical soil properties were also presented in the papers by Debska et al. (2010) and Pypers et al. (2011).

Table 3

The content of available magnesium and $S-SO_4$ in soil upon fertilization 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	x	50	100	200	400	x	1	2	3	4	x	
mg Mg (kg^{-1} d.m.)																
0-25	14.0	17.7	21.7	31.7	21.3	13.3	14.7	20.0	22.7	17.7	20.3	22.3	25.7	33.7	25.5	21.5
26-50	32.7	35.7	48.7	58.7	43.9	27.3	29.3	38.3	38.3	33.3	33.3	32.3	37.7	43.3	36.7	38.0
51-75	62.0	62.0	66.7	74.0	66.2	49.7	54.3	60.0	68.7	58.2	62.0	53.3	48.3	38.7	50.6	58.3
76-100	70.0	57.3	77.3	58.7	65.8	62.7	60.0	56.7	52.7	58.0	66.0	75.3	58.7	52.0	63.0	62.3
Mean	44.7	43.2	53.6	55.8	49.3	38.3	39.6	43.8	45.6	41.8	45.4	45.8	42.6	41.9	44.0	45.0
HSD (0.05) (fertilization type) – 4.3; (depth×fertilzation type) – 11.9; (fertilisation type×fertilization rate) – 20.5; (depth×fertilization type×fertilization rate) – 26.0																
mg $S-SO_4$ (kg^{-1} d.m.)																
0-25	4.93	6.83	29.00	12.80	13.40	7.28	9.73	5.35	5.43	6.95	3.90	20.9	10.0	14.6	11.6	10.6
26-50	4.79	3.07	9.45	5.03	5.58	10.10	7.07	3.62	1.17	5.49	9.02	10.0		12.4		6.82
51-75	2.93	4.47	6.15	3.73	4.32	8.15	7.17	4.92	6.55	6.70	13.6	10.6	12.3	14.3	12.7	7.91
76-100	3.32	4.47	6.57	6.43	5.22	8.87	8.25	6.62	7.70	7.75	10.2	11.6	12.6	14.5	12.2	8.40
Mean	3.99	4.73	12.80	7.00	7.13	8.60	8.05	5.01	5.21	6.72	9.18	13.3	10.3	14.0	11.5	8.43
HSD (0.05) (fertilization type) – 1.63; (depth×fertilzation type) – 4.36; (fertilisation type×fertilization rate) – 4.26; (depth×fertilization type×fertilization rate) – 6.25																

Table 4

The content of iron and manganese soluble in 1 M HCl dm^{-3} in the soil upon fertilization 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	x	50	100	200	400	x	1	2	3	4	x	
mg Fe (kg^{-1} d.m.)																
0-25	773.3	799	796	814	796	729	711	797	889	781	726	830	760	852	792	790
26-50	745.0	734	635	664	694	653	719	697	669	685	709	750	726	732	729	703
51-75	919.7	928	846	679	843	841	953	833	764	847	943	1027	1051	971	998	896
76-100	1009.3	937	935	800	920	920	958	966	838	921	978	1091	1130	1084	1071	971
Mean	861.8	850	803	739	813	786	835	823	790	809	839	925	917	910	898	840
HSD (0.05) (fertilization type) – 32; (depth×fertilization type) – 86; (fertilization type×fertilization rate) – 130; (depth×fertilization type×fertilization rate) – 171																
mg Mn (kg^{-1} d.m.)																
0-25	93.6	96.8	87.7	95.9	93.5	74.3	79.0	89.0	101.4	85.9	87.7	88.8	89.7	79.2	86.3	88.6
26-50	55.1	59.6	51.3	65.2	57.8	49.7	56.2	58.7	67.0	57.9	58.0	58.5	64.6	81.0	65.5	60.4
51-75	66.2	64.4	58.6	61.5	62.7	58.2	68.3	68.5	75.4	67.6	64.8	81.0	73.2	72.8	72.9	67.7
76-100	59.4	54.2	54.4	53.6	55.4	55.8	60.6	63.4	69.6	62.4	62.0	73.3	75.4	66.9	69.3	62.4
Mean	68.6	68.8	63.0	69.1	67.4	59.5	66.0	69.9	78.4	68.5	68.1	75.4	75.7	75.0	73.5	69.8
HSD (0.05) (fertilization type) – 3.6; (depth×fertilization type) – 10.1; (fertilization type×fertilization rate) – 14.5; (depth×fertilization type×fertilization rate) – 21.7																

CONCLUSIONS

1. Fertilization with liquid manure applied annually and biennially (double doses) and with mineral fertilizers resulted in a steady, significant increase in the content of nutrients (particularly in the topsoil layer), including available phosphorus, potassium, and magnesium, and in pH_{KCl} (only in the case of liquid manure) and organic carbon.

2. The highest concentrations of available phosphorus, soluble manganese and $S\text{-}SO_4$ were found in the 0-25 cm layer, irrespective of the type of fertilization applied; the content of the available forms of potassium and magnesium increased along with the depth of the profile, especially downwards to 75 cm.

3. Annual and biennial (double dose) application of liquid manure and of equivalent amounts of mineral fertilizers resulted in a similar increase in the nutrient content (the phenomenon was not always confirmed by statistical calculations) and in pH_{KCl} and $C_{org.}$

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