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CONTENT, UPTAKE AND UTILIZATION BY PLANTS OF COPPER, MANGANESE AND ZINC FROM MUNICIPAL SEWAGE SLUDGE AND WHEAT STRAW

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Abstract

In a two-factor pot experiment, which was conducted 2004-2005, the direct and successive impact was estimated of mixed application of different doses of municipal sewage sludge (0.5, 1.0, 1.5 and 2.0% d.m. of sewage sludge relative to 6 kg d.m. soil in pot) and a constant dose of wheat straw (30 g d.m. per pot), with and without supplemental mineral fertilization with nitrogen and NPK, on the content, uptake and utilization of copper, manganese and zinc by test plants.

The soil used in the experiment was brown acid incomplete soil (good rye complex) and the test plant in the first year of research was grass – *Festulolium*, which was harvested four times, and in the second year – common sunflower and blue phacelia.

In mean object samples of *Festulolium*, common sunflower and phacelia, content of copper, manganese and zinc was marked with the ASA method after mineralization in a mixture of nitric (V) and perchloric acid (VII).

Rising doses of municipal sewage sludge with addition of a fixed dose of wheat straw, both in direct and successive effect, increased the content of copper, manganese and zinc in test plants.

The increase in the weighted mean (from four swaths) content of copper in *Festulolium,* in comparison with the control object, varied from 8.04 to 59.8%, manganese from 21.8 to 68.8% and zinc from 19.4 to 59.1%. In the second year, the mean increase in the content of copper in common sunflower from objects fertilized with sewage sludge and straw varied from 8.7 to 30.3% and in phacelia from 6.1 to 12.6%. By analogy, the mean content of manganese rose from 23.3 to 59.5% and from 5.9 to 33.1% and the content of zinc from 33.2 to 50.3% and from 15.9 to 37.9%. Mineral fertilization with N and NPK,

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in comparison with the object without that fertilization, in both years of the experiment, increased the mean content of all microelements in test plants, with the increase being larger after NPK than N fertilization.

The uptake of microelements by plants from sewage sludge and straw, in most cases, was increasing along with the increase of the doses of sewage sludge. In the total uptake of individual microelements, about 2/3 were atken up by *Festulolium* and the remaining 1/3 by phacelia. Utilization of individual microelements from sewage sludge and straw was considerably diverse. IIn the two years, test plants utilized manganese mostly (on average 58.2%), less zinc (on average 5.54%) and to the smallest degree copper (on average 3.03%).

Key words: sewage sludge, wheat straw, test plants, copper, manganese, zinc.

ZAWARTOŚĆ, POBRANIE I WYKORZYSTANIE PRZEZ ROŚLINY TESTOWE MIEDZI, MANGANU I CYNKU Z KOMUNALNEGO OSADU ŚCIEKOWEGO I SŁOMY PSZENNEJ

Abstrakt

W dwuczynnikowym doświadczeniu wazonowym, przeprowadzonym w latach 2004-2005, oceniano wpływ bezpośredni i następczy łącznego stosowania zróżnicowanych dawek komunalnego osadu ściekowego (0,5, 1,0, 1,5 i 2,0% s.m. osadu w stosunku do 6 kg s.m. gleby w wazonie) i stałej dawki słomy pszennej (30 g s.m. na wazon), bez i z dodatkowym nawożeniem mineralnym azotem i NPK, na zawartość, pobranie i wykorzystanie miedzi, manganu i cynku przez rośliny testowe. Podłoże w doświadczeniu stanowiła gleba brunatna kwaśna, niecałkowita (kompleks żytni dobry), a rośliną testową w pierwszym roku badań była trawa – *Festulolium*, którą zebrano czterokrotnie, a w drugim roku słonecznik zwyczajny i facelia błękitna. W średnich próbkach obiektowych *Festulolium,* słonecznika i facelii oznaczono, po mineralizacji w mieszaninie kwasu azotowego (V) i chlorowego (VII), zawartość miedzi, manganu i cynku metodą ASA.

Wzrastające dawki komunalnego osadu ściekowego z dodatkiem stałej dawki słomy pszennej zarówno w działaniu bezpośrednim, jak i następczym, zwiększyły zawartość miedzi, manganu i cynku w roślinach testowych. Wzrost średniej ważonej (z czterech pokosów) zawartości miedzi w *Festulolium,* w porównaniu z obiektem kontrolnym, wahał się od 8,04 do 59,8%, manganu od 21,8 do 68,8%, a cynku od 19,4 do 59,1%. W drugim roku badań, w słoneczniku zebranym z gleby nawożonej osadem i słomą, średni wzrost zawartości miedzi wahał się od 8,7 do 30,3%, a w facelii od 6,1 do 12,6%, manganu odpowiednio od 23,3 do 59,5% i od 5,9 do 33,1%, a cynku od 33,2 do 50,3% i od 15,9 do 37,9%. Nawożenie mineralne N i NPK, w stosunku do obiektu bez tego nawożenia, w obu latach badań zwiększyło średnią zawartość wszystkich analizowanych mikroelementów w roślinach testowych, z tym że NPK w większym stopniu niż N. Pobranie mikroelementów przez rośliny z osadu i słomy, w większości przypadków, zwiększało się wraz ze wzrostem dawek osadu ściekowego. W całkowitym pobraniu poszczególnych mikroelementów udział *Festulolium* stanowił ok. 2/3, a słonecznika i facelii ok. 1/3. Wykorzystanie poszczególnych mikroelementów z osadu i słomy było znacznie zróżnicowane. W okresie dwóch lat w największym stopniurośliny testowe wykorzystały mangan (średnio 58,2%), w mniejszym cynk (średnio 5,54%), a w najmniejszym miedź (średnio 3,03%).

Słowa kluczowe: osad ściekowy, słoma pszenna, rośliny testowe, miedź, mangan, cynk.

INTRODUCTION

Environmental utilization, including agricultural use, of sewage sludge has recently increased but is still arousing many reservations, mainly due to possible microbiological and chemical contamination of soils, greasy consistency and odour of sewage sludge. Taking into consideration the fertilizing value of sewage sludge, confirmed by the research on its chemical composition (MAĆKOWIAK 2001, SPIAK, KULCZYCKI 2004) and impact on crop yield and soil fertility (CZEKAŁA 2000, WOŁOSZYK et al. 2005, 2006, GRZYWNOWICZ 2007, JASIEWICZ ET al. 2007, SULEWSKA, KOZIARA 2007, BOWSZYS et al. 2009), it seems that sewage sludge should be used for soil and plant fertilizing. It gains more importance as production of natural fertilizers declines and significantly less mineral fertilizers are used due to their rising prices.

About 40% area of soils in Poland is poor in copper and 10% has little manganese and zinc. This should be treated as a signal for utilization of alternative sources of these microelements, for example sewage sludge. With the current production of sewage sludge (about 500 thousand t d.m. in 2006, Rocznik Statystyczny 2007) and mean content of 135 mg $Cu \cdot kg^{-1}$ d.m., 325 mg $Mn \cdot kg^{-1}$ d.m. and 1350 mg $Zn \cdot kg^{-1}$ d.m. (MAĆKOWIAK 2001), about 68 t of copper, 163 t of manganese and 675 t of zinc annually could be received.

The aim of the research was to evaluate direct and successive impact of different doses of sewage sludge and a constant dose of wheat straw with and without supplemental mineral fertilization with nitrogen and NPK, on the content, uptake and utilization of copper, manganese and zinc by test plants.

MATERIAL AND METHODS

In 2004-2005, a pot experiment was conducted under a polyethylene roof at the Vegetation Hall of Vegetation of University of Agriculture in Szczecin. The soil used in the experiment was taken from the Ap level of a production field at the Experimental Agricultural Station in Lipnik. The soil represented acid brown incomplete soil of the grain size distribution characteristic of light, very fine sand with 12% of slit and clay (good rye complex). Potential of hydrogen of the soil before setting up the experiment was acid (pH in 1 M $KCl \cdot dm^{-3}$ – 5,31); the content of total carbon was 6.03 $g \cdot kg^{-1}$ and that of total nitrogen was 0.60 $g \cdot kg^{-1}$; the soil was rich in available phosphorus and zinc, moderately abudant in potassium, copper and manganese, poor in magnesium.

The design of the experiment included two factors. The first factor comprised 5 variants: control and 4 doses of municipal sewage sludge with addition of an equal dose of wheat straw, and the second factor consisted of a variant without mineral fertilization (0), with mineral fertilization (N) and with NPK. Doses of municipal sewage sludge were 0.5, 1.0, 1.5 and 2.0% d.m. in relation to 6.0 kg d.m. soil in a pot. Wheat straw, cut in chaff, was applied in a dose of 30 g d.m. per pot. Sewage sludge came from a mechanical and biological sewage treatment plant in Stargard Szczeciński. The content of heavy metals was lower than norms set for agricultural utilization of sewage sludge (Rozporządzenie 2002). Table 1 shows chemical composition of sewage sludge and straw.

Table 1

Chemical composition of municipal sewage sludge and wheaten straw

Specification	Dry matter ($g \cdot kg^{-1}$)	Total content					
		$g \cdot kg^{-1}$ d.m.			$mg \cdot kg^{-1}$ d.m.		
		N	P	K	Cu	Mn	Zn
Sewage sludge	175	65.6	21.6	5.01	148	349	825
Wheat straw	900	4.90	1.10	13.2	3.13	40.0	12.8

For the objects fertilized only with mineral nitrogen and NPK, the dose of nitrogen was 1 g N per pot (urea – 46% N), which was applied as 0.25 g N per pot before sowing of *Festulolium* and after harvest of the 1st, 2nd and 3rd swath. Phosphorus (double superphosphate – 20% P) in the objects with NPK was applied once as 0.164 g P and potassium (potash salt – 50% K) 0.104 g K per pot before sowing and after the 1st and the 2nd swath. The test plant was an intergenus hybrid, *Festulolium* (var. Felopa), which was sown on 28.04.2004 and harvested on 18.06 (I), 19.07 (II) 25.08 (III) and 28.09.2004 (IV). During the whole growing season, grass was watered with distilled water, keeping soil humidity at a 60% level of full water capacity. After the fourth cut of *Festulolium*, soil was mixed in pots and the stubble mulch was covered, which prepared pots to be stored until spring 2005. On 19th of April 2005 pots were placed under a polyethylene roof and after loosening the soil in pots, water solutions of mineral fertilizers were applied. On the objects with mineral fertilization, the dose of nitrogen was 0.25 g N (urea – 46% N), phosphorus – 0.164 g P (double superphosphate – 20% P) and 0.208 g K per pot (potash salt – 50% K). Test plant was common sunflower (10 seeds per pot, 7 plants were left after thinning), which was sown on 22nd of April 2005. The second dose of nitrogen (0.25 g N per pot), on the objects with N and NPK fertilization, was applied on 20th of May 2005. Common sunflower was harvested on 16th of June 2005 and fresh and dry matter yield wasdetermined. Afterwards, the soil in pots was loosened and on 21st of June 2005 blue phacelia was sown as a test plant. Twenty plants were left after the seedlings. At the same time, on the objects fertilized with N and NPK, 0.25 g N was applied per pot (water solution of urea – 46% N). Phacelia was harvested on 28th of August and fresh and dry matter yield wasdetermined. After the harvests of grass swaths, common sunflower and blue phacelia, mean object samples of individual plants were mineralized in a mixture (3:1) of nitric (V) and perchloric acid (VII) and total content of copper, manganese and zinc was determined with the ASA method. Results of the content of microelements and their uptake by plants were statistically studied with analysis of variance for a two-factor, no-replication system according to FR – Analwar – 4.3 packet. Multiple comparison of means was conducted on the basis of Tukey's procedure at p=0.01.

RESULTS AND DISCUSSION

Direct and successive impact of rising doses of municipal sewage sludge and a constant dose of wheat straw with and without mineral N and NPK fertilizing on yield was shown in previous paper (WOŁOSZYK et al. 2006). In direct impact all of the doses of sewage sludge (from 0.5 to 2.0% d.m. of sewage sludge in relation to 6 kg d.m. soil per pot) with addition of an equal dose of wheat straw (30 g d.m. per pot) significantly increased sum of yield of *Festulolium* from four swaths in comparison with the control object. Mean increases of dry matter yield varied from 98% to 259%. Fertilizing with mineral nitrogen, applied alongside sewage sludge and straw, in relation to objects without mineral fertilization, increased yield of *Festulolium* by about 27.4% and fertilizing with NPK – by about 38.4%. on average In successive impact of sewage sludge and straw, mean increases of sum of dry matter of sunflower and phacelia varied from 17.9% to 44.2%. However, supplemental fertilization with nitrogen increased yield of sunflower and phacelia by about 15.7% and with NPK by about 35.5%.

Total fertilization with rising doses of municipal sewage sludge and an equal dose of wheat straw increased content of copper, manganese and zinc in *Festulolium* as well as in sunflower and phacelia (Table 2). It should be mentioned that the main source of the analyzed microelements was sewage sludge, because the contribution of straw to the amount of incorporated components, with rising doses of sewage sludge, was from 2.12 to 0.53% for copper, from 11.5% to 2.86% for manganese and from 1.55% to 0.39% for zinc.

The mean weighted (from four swaths) content of copper in *Festulolium*, in most cases, was increasing along with the increase of doses of sewage sludge (Table 2). Mean increases of content of copper varied from 8.04 to 59.8%, in comparison with the control object (without sewage sludge and straw). Favourable influence of mineral fertilization on the copper content in grass was also noticed. On objects with mineral nitrogen fertiliza-

Table 2

Weighted mean (of 4 cuts) content of copper, manganese and zinc in *Festulolium* and content in common sunflower a blue phacelia (mg·kg^{-1}d.m.)

Object	Without fertilization			N			NPK			Mean		
	Cu	Mn	Zn	Cu	Mn	Zn	Cu	Mn	Zn	Cu	Mn	Zn
Festulolium												
Control	3.53	120	31.8	3.85	170	33.4	4.56	220	35.2	3.98	170	33.5
Sludge 0.5%+straw	3.70	160	36.7	4.07	210	40.1	5.13	250	43.1	4.30	207	40.0
Sludge 1.0%+straw	3.96	180	44.6	4.52	220	49.9	6.65	260	53.3	5.04	220	49.2
Sludge 1.5%+straw	4.81	230	47.7	5.63	270	55.0	6.62	310	57.2	5.68	270	53.3
Sludge 2.0%+straw	5.40	250	48.0	6.39	280	54.3	7.31	330	57.3	6.36	287	53.2
Mean	4.28	188	41.8	4.89	230	46.5	6.05	274	49.2	5.07	231	45.8
$LSD_{0.01}$(for doses of sewage sludge)										n.s.	n.s.	17.0
Common sunflower												
Control	4.60	162	34.9	4.72	162	36.6	4.85	164	35.8	4.72	163	35.8
Sludge 0.5%+straw	4.90	181	39.1	5.15	208	51.2	5.36	215	52.9	5.13	201	47.7
Sludge 1.0%+straw	5.10	198	44.0	5.40	212	52.2	5.57	227	54.6	5.35	212	50.3
Sludge 1.5%+straw	5.32	227	46.8	5.55	232	53.8	5.78	254	56.8	5.55	238	52.5
Sludge 2.0%+straw	5.90	245	48.6	6.15	260	54.5	6.42	274	58.2	6.15	260	53.8
Mean	5.16	203	42.7	5.39	215	49.7	5.59	227	51.7	5.38	215	48.0
$LSD_{0.01}$(for doses of sewage sludge)										0.95	58.9	n.s.
Blue phacelia												
Control	4.40	168	34.2	4.50	170	34.9	4.45	170	33.0	4.45	169	34.0
Sludge 0.5%+straw	4.56	176	36.5	4.76	181	40.4	4.85	181	41.2	4.72	179	39.4
Sludge 1.0%+straw	4.65	191	40.2	4.82	194	43.4	4.92	207	42.9	4.79	197	42.2
Sludge 1.5%+straw	4.78	200	42.2	4.90	208	45.9	4.98	218	46.6	4.88	209	44.9
Sludge 2.0%+straw	4.90	218	45.1	5.00	224	47.4	5.15	234	48.2	5.01	225	46.9
Mean	4.66	191	39.6	4.79	195	42.4	4.87	202	42.4	4.77	196	41.4
$LSD_{0.01}$(for doses of sewage sludge)										0.57	28.5	8.19

tion, in comparison with an object without fertilization, mean content of copper was 14.2% higher and on objects with NPK fertilization it was 41.4% higher. Content of manganese in *Festulolium* was increasing along with rising doses of sewage sludge on objects without mineral fertilization as well as with nitrogen fertilization and NPK (tab. 2). Mean increases of that element on objects with sewage sludge and straw, in relation to the control, varied from 21.8 to 68.8%. The highest mean content of manganese, similarly to that of copper, was determined in grass harvested from soil fertilized with NPK (274 mg $Mn \cdot kg^{-1}$ d.m.), lower from soil with nitrogen (230 mg $Mn \cdot kg^{-1}$ d.m.) and the lowest from objects with soil without mineral fertilization (188 mg $Mn \cdot kg^{-1}$ d.m.). All of the doses of sewage sludge and straw, in comparison with the control, considerably increased the mean content of zinc in *Festulolium* (from 19.4 to 59.1%). In grass from objects with 1.5% d.m. and 2.0% d.m. doses of sewage sludge, in relation to soil mass in a pot, the content of zinc was almost identical (53.3 and 53.2 mg $Zn \cdot kg^{-1}$ d.m.) and significantly higher in relation to the control. Supplemental mineral fertilization with nitrogen and NPK, as in the case of copper and manganese, increased the content of zinc in grass suitably about 11.2 and 17.7%, but these differences were not statistically confirmed (Table 2).

As a result of the successive impact of sewage sludge and straw, the content of copper, manganese and zinc in common sunflower and blue phacelia increased (Table 2). The mean content of the analyzed microelements in sunflower was similar to the content in *Festulolium* and lower in phacelia. In turn, rising doses of sewage sludge, versus the control, increased the mean content of copper in sunflower from 8.69 to 30.3% and in phacelia from 6.07 to 12.6%, that of manganese, respectively, from 23.3 to 50.5 and from 5.92 to 33.1%, zinc – from 33.2 to 50.3% and from 15.9 to 37.9%. However, significant increase in the content of copper in sunflower and phacelia was obtained under the influence of the highest dose of sewage sludge and that of manganese as a result of 1.5% and 2.0% d.m. of sewage sludge application. However, the content of zinc in sunflower did not significantly differ. In phacelia, there was more zinc than in the control from the second dose of sewage sludge on. Mineral fertilizing with nitrogen and NPK did not cause such a considerable increase in the content of microelements in sunflower and phacelia as in the case of *Festulolium*. It was only the content of zinc in sunflower from the objects with supplemental nitrogen and NPK fertilization that increased quite considerably (on average about 16.4 and 21.1%).

Statistical analysis showed significant differences in the uptake of copper and manganese by *Festulolium* between the control and the highest dose of sewage sludge, while the uptake of zinc was significantly different after application of 1.5 and 2.0% d.m. of sewage sludge. However, the differences in the uptake of the analyzed microelements by sunflower and phacelia were not statistically confirmed (Table 3). Yet, when analyzing the mean

Table 3

Uptake of microelements by *Festulolium*, common sunflower and blue phacelia (mg from pot)

Object	Copper (Cu)				Manganese (Mn)				Zinc (Zn)			
	0	N	NPK	$\overline{x}$	0	N	NPK	$\overline{x}$	0	N	NPK	$\overline{x}$
Festulolium												
Control	0.020	0.111	0.168	0.100	0.68	4.88	8.12	4.56	0.18	0.96	1.30	0.81
Sludge 0.5%+straw	0.128	0.205	0.290	0.208	5.52	10.56	14.16	10.08	1.27	2.02	2.44	1.91
Sludge 1.0%+straw	0.207	0.322	0.463	0.331	9.42	15.68	18.10	14.40	2.33	3.56	3.71	3.20
Sludge 1.5%+straw	0.346	0.439	0.555	0.447	16.53	21.05	25.98	21.19	3.43	4.29	4.79	4.17
Sludge 2.0%+straw	0.435	0.534	0.672	0.547	20.15	23.40	30.33	24.63	3.87	4.54	5.27	4.56
Mean	0.227	0.322	0.430	0.326	10.46	15.11	19.34	14.97	2.22	3.07	3.50	2.93
$LSD_{0.01}$(for doses of sewage sludge)				0.443				19.32				2.85
Sunflower and phacelia												
Control	0.075	0.110	0.135	0.106	2.71	3.92	4.78	3.80	0.57	0.85	1.00	0.81
Sludge 0.5%+straw	0.107	0.129	0.170	0.135	4.02	5.07	6.64	5.24	0.86	1.20	1.59	1.22
Sludge 1.0%+straw	0.122	0.154	0.188	0.154	4.84	6.12	7.77	6.24	1.05	1.45	1.77	1.42
Sludge 1.5%+straw	0.142	0.164	0.187	0.164	6.02	6.91	8.20	7.04	1.25	1.57	1.80	1.54
Sludge 2.0%+straw	0.176	0.181	0.210	0.189	7.48	7.84	9.15	8.16	1.51	1.65	1.92	1.69
Mean	0.124	0.148	0.178	0.150	5.01	5.97	7.31	6.10	1.05	1.34	1.62	1.34
$LSD_{0.01}$(for doses of sewage sludge)				n.s				n.s.				n.s.
Sum of uptake by three plants												
Control	0.095	0.220	0.303	0.206	3.39	8.80	12.90	8.36	0.75	1.81	2.30	1.62
Sludge 0.5%+straw	0.235	0.333	0.460	0.343	9.54	15.63	20.80	15.32	2.12	3.22	4.03	3.13
Sludge 1.0%+straw	0.329	0.477	0.651	0.486	14.26	21.80	25.87	20.64	3.39	5.01	5.48	4.62
Sludge 1.5%+straw	0.488	0,603	0.742	0.611	22.55	27.96	34.18	28.23	4.68	5.86	6.60	5.71
Sludge 2.0%+straw	0.611	0.715	0.881	0.736	27.63	31.24	39.48	32.79	5.37	6.19	7.19	6.25
Mean	0.351	0.470	0.608	0.476	15.47	21.08	26.65	21.07	3.27	4.41	5.12	4.27
$LSD_{0.01}$(for doses of sewage sludge)				n.s.				24.17				4.00

uptake of microelements in relative numbers, there was a considerable dependence on the dose of ewage sludge and mineral fertilization was noticed.

The mean uptake of all the microelements by *Festulolium*, even at the lowest dose of sewage sludge, was over two-fold higher than in the control and from the soil with the highest dose of sewage sludge the uptake of copper and manganese was about 5-fold and zinc about 6-fold higher. From the soil fertilized with nitrogen, grass took up about 40% more microelements and from the soil with NPK – about 89.4 more copper, 84.4 more manganese and 57.6% more zinc. The total uptake of microelements by yield of sunflower and phacelia was increasing as doses of sewage sludge increased, but the increments were considerably lower than of *Festulolium*. The uptake of copper from soil with the lowest dose of sewage sludge, in comparison with the control, was about 27.4% higher, manganese about 37.9% higher and zinc about 50.6%, while from the soil with the highest dose – about 78.3, 114.7 and 108.6% higher, respectively. In the objects fertilized with nitrogen, the uptake of copper and manganese was about 19% and with NPK about 45% higher in relation to objects without fertilization, while the uptake of zinc was 27.6 and 54.3% higher.. The lowest uptake by test plants in the two years of the experiment was that of copper (on average 0.476 mg per pot), the uptake of zinc was higher (on average 4.27 mg per pot) and the highest uptake was that of manganese (on average 21.07 mg per pot; Table 3).

On the basis of the mean uptake of microelements by yield of test plants from sewage sludge and straw as well as the amount of components incorporated with those fertilizers, utilization of copper, manganese and zinc by *Festulolium*, sunflower, phacelia and total utilization by three plants was estimated (Table 4). The mean utilization of copper, manganese and zinc by test plants from individual doses of sewage sludge and the constant dose of straw was hardly diverse. The mean utilization of copper by *Festulolium* varied from 2.38 to 2.59%, manganese from 44.44 to 50.99% and zinc from 3.77 to 4.79%. Utilization of microelements by sunflower and phacelia was several-fold lower and in the case of copper varied from 0.43 to 0.64%, manganese from 9.94 to 12.34% and zinc from 0.88 to 1.63%. Lower utilization of microelements from sewage sludge and straw by sunflower and phacelia was connected with lower dry matter yield of those plants, in comparison with *Festulolium*, because the content of individual components did not differ considerably. Utilization of copper (3.03%) and zinc (5.54%) from sewage sludge over the two years should be consider as low and manganese (58.18%) as high.

The present research confirms favourable influence of municipal sewage sludge, noticed by other authors (Jasiewicz et al. 2006, Ailinacai et al. 2007), on shaping the content of microelements in plants. It was also stated that mineral fertilization with nitrogen and NPK modified the content of microelements in plants. Positive impact of mineral fertilization with nitrogen, ap-

Table 4

Amount of microelements brought into soil, taken up and utilized by test plants

Object	Amount of microelements brought into soil with sewage sludge and straw (mg pot^{-1})			Amount of microelements taken up by plants from sewage sludge and straw (mg pot^{-1})			Utilization of micro-elements from sewage sludge and straw by test plants (%)		
	Cu	Mn	Zn	Cu	Mn	Zn	Cu	Mn	Zn
Festulolium									
Sludge 0.5%+straw	4.53	11.67	25.13	0.108	5.52	1.10	2.38	47.30	4.38
Sludge 1.0%+straw	8.97	22.14	49.88	0.231	9.84	2.39	2.58	44.44	4.79
Sludge 1.5%+straw	13.41	32.61	74.63	0.347	16.63	3.36	2.59	50.99	4.50
Sludge 2.0%+straw	17.85	43.08	99.38	0.447	20.07	3.75	2.50	46.59	3.77
Sunflower and phacelia									
Sludge 0.5%+straw	4.53	11.67	25.13	0.029	1.44	0.41	0.64	12.34	1.63
Sludge 1.0%+straw	8.97	22.14	49.88	0.048	2.44	0.61	0.53	11.02	1.22
Sludge 1.5%+straw	13.41	32.61	74.63	0.058	3.24	0.73	0.43	9.94	0.98
Sludge 2.0%+straw	17.85	43.08	99.38	0.083	4.36	0.88	0.47	10.12	0.88
Sum									
Sludge 0.5%+straw	4.53	11.67	25.13	0.137	6.96	1.51	3.02	59.64	6.01
Sludge 1.0%+straw	8.97	22.14	49.88	0.279	12.28	3.00	3.11	55.46	6.01
Sludge 1.5%+straw	13.41	32.61	74.63	0.405	19.87	4.09	3.02	60.93	5.48
Sludge 2.0%+straw	17.85	43.08	99.38	0.530	24.43	4.63	2.97	56.71	4.65

plied against the background of manure, on the content of copper, manganese and zinc in different stages of development of spring barley was confirmed by Rabikowska et al. (2000).

Low utilization of copper and zinc from municipal sewage sludge by plants in a period of three years has been proved in an earlier field study by Wołoszyk et al. (2004). High utilization of manganese from sewage sludge, especially by *Festulolium*, could be a result of high absorption of these element by plants from the soil characterized by acid reaction.

CONCLUSIONS

1. Total fertilization with rising doses of municipal sewage sludge and an equal dose of wheat straw, in comparison with the control objects, resulted in an increase in the content of copper, manganese and zinc in *Festulolium* (direct impact) as well as in sunflower and phacelia (successive impact).

2. Mineral fertilization with nitrogen and NPK, applied against the background of sewage sludge with straw, increased the content of microelements in test plants, especially in the first year of research.

3. The uptake of the analyzed microelements by test plants was increasing along with rise of the doses of sewage sludge and under the influence of mineral fertilizing. In the total uptake of individual microelements, 2/3 were taken up by *Festulolium* and 1/3 by sunflower and phacelia.

4. Utilization of individual microelements from sewage sludge and straw was quite diverse. Over the two years, manganese was utilized to the highest degree (on average 58.2%), followed by zinc (on average 5.54%) and copper (on average 3.03%).

REFERENCE

AILINACAI C., JITAREANU G., BUCUR D., AILINACAI D. 2007. *Influence of sewage sludge on maize yield and quality and soil chemical characteristics.* J. Food, Agric. Environ., 5(1): 310-313.

BOWSZYS T., WIERZBOWSKA J., BOWSZYS J. 2009. *Content and removal of Cu and Zn with harwested crops grown on soil fertilized with composted municipal sewage sludge.* J. Elementol., 14(1): 23-32.

CZEKAŁA J. 2000. *Wartość próchnicotwórcza i działanie nawozowe osadu ściekowego [Humus formation value and fertilizing activity of sewage sludge].* Fol. Univ. Agric. Stein. Agricult., 211(84): 75-80. [in Polish]

GRZYWNOWICZ I. 2007. *Dynamics of changes of mineral nitrogen form content in soil after application of sewage sludge as fertilizer.* Ecol. Chem. Eng., 14(3-4): 303-308.

JASIEWICZ CZ., ANTONKIEWICZ J., BARAN A. 2006. *Influence of organic fertilizers on heavy metal content in tall oat grass.* Ecol. Chem. Eng., 13(9): 915-923.

JASIEWICZ CZ., ANTONKIEWICZ J., MAZUR Z., MAZUR T., KRAJEWSKI W. 2007. *Agrochemical properties of soil fertilized with sewage sludge from sewage treatment plant at Olecko.* Ecol. Chem. Eng., 14(5-6): 457-463.

MAĆKOWIAK CZ. 2001. *Wartość nawozowa osadów ściekowych [Fetilizing value of sewage sludge].* Inż. Ekol., 3: 135-145. [in Polish]

RABIKOWSKA B., PISZCZ U., BELICZYŃSKA K. 2000. *Wpływ wieloletniego nawożenia obornikiem i azotem na zawartość miedzi, manganu i cynku w niektórych fazach rozwojowych jęczmienia jarego [effect of long-term fertilization with manure and nitrogen on the content of manganese and zinc in some developmental phases of spring barley].* Zesz. Prob. Post. Nauk Rol., 471: 495-504. [in Polish]

Rocznik Statystyczny. *Ochrona Środowiska [Environmental Protection*. 2007. GUS, Warszawa. [in Polish]

Rozporządzenie Ministra Środowiska z dnia 1 sierpnia 2002 r. *w sprawie komunalnych osadów ściekowych.* DzU z 2002 r. nr 134, poz. 1140. [Oridnance of the Minister for Environment of 1 August 2002 on municipal sewage sludge. Journal of Law, 2002, no 134, item 1140] [in Polish]

SPIAK Z., KULCZYCKI G. 2004. *Zawartość mikroelementów w osadach ściekowych z wybranych oczyszczalni województwa dolnośląskiego [Content of micronutrients in sewage sludge from some wastewater treatment plants in Dolnośląskie Province].* Zesz. Prob. Post. Nauk Rol., 502(2): 973-978. [in Polish]

SULEWSKA H, KOZIARA W. 2007. *Produkcja osadów ściekowych w Polsce i efekty ich stosowania w uprawie kukurydzy [Sewage sludge production in Poland and effects of sewage sludge fertilization on maize plantations].* Zesz. Prob. Post. Nauk Rol., 518: 175-183. [in Polish]

WOŁOSZYK CZ., IŻEWSKA A., KRZYWY-GAWROŃSKA E. 2004. *Zawartość, pobranie i wykorzystanie mikroelementów z kompostów przez rośliny w trzyletnim zmianowaniu [Content, uptake and utilization of micronutrients from composts by crops in a three-year rotation system].* Zesz. Prob. Post. Nauk Rol., 502: 1059-1067. [in Polish]

WOŁOSZYK CZ., KRZYWY E., IŻEWSKA A. 2005. *Ocena wartości nawozowej kompostów sporządzonych z komunalnego osadu ściekowego w trzyletnim zmianowaniu roślin [Evaluation of fertilization value of composts made from municipal sewage sludge in a three-year rotation of crops].* Frag. Agronom., 1(85): 633-642. [in Polish]

WOŁOSZYK CZ., KRZYWY E., IŻEWSKA A., KRZYWY-GAWROŃSKA E., BALCER K. 2006. *Wpływ bezpośredni i następczy komunalnego osadu ściekowego i słomy pszennej na wielkość plonu oraz na zawartość makroskładników w roślinach testowych [Direct and successive effect pf municipal sewage sludge and wheat straw on yield volume and content of macronutrients in test plants].* Zesz. Prob. Post. Nauk Rol., 512: 211-220. [in Polish]