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MODIFICATIONS OF PHYSICO-CHEMICAL SOIL PROPERTIES FOLLOWING APPLICATION OF SEWAGE SLUDGE AS SOIL AMENDMENT

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Abstract

The results of a pot experiment on soil application of sewage sludge samples (at the rate of 200 g DM · pot^{-1}) from 19 sewage treatment plants localized in region of the Green Lungs of Poland in three areas: the Great Masurian Lakes, Iława Ostróda Lake District and Łyna River Basin, are discussed in the paper. The sewage treatment plants had different capacities, received different shares of industrial sewage water and used different technologies of sewage sludge dewatering. In the pot experiment the following five vegetable crops were grown (without winter break): root celery, lettuce, small radish, Swiss chard and spinach. Before planting the first plant (celery) and after harvesting the last plant in the rotation (spinach), physical and chemical properties of the soil were studied in order to determine if the amendment of soil with sewage sludge could pose any environmental risk to the growth of vegetable crops. It was found that most of the applied samples of sewage sludge did not produce adverse effects on the determined parameters. In many cases, the content of organic carbon increased soil retention properties were improved under the effect of sewage sludge. Sewage sludge form Zalewo, because of its high content of chromium, was implied as being hazardous for growing plants, as it could result in soil and plant contamination. When sewage sludge from Olsztyn, Olsztynek and Spychowo was applied to soil, zinc contamination occurred.

Key words: sewage sludge, water treatment plants in east-northern Poland, soil properties, trace metals.

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ZMIANY FIZYKOCHEMICZNYCH WŁAŚCIWOŚCI GLEBY W NASTĘPSTWIE ROLNICZEGO STOSOWANIA OSADÓW ŚCIEKOWYCH

Abstrakt

W pracy przedstawiono wyniki doświadczenia wazonowego z zastosowaniem osadów ściekowych, w jednakowej dawce 200 g s.m.$\cdot$wazon^{-1}, pobranych z 19 oczyszczalni ścieków zlokalizowanych na obszarze tzw. Zielonych Płuc Polski w trzech regionach geograficznych: Wielkich Jezior Mazurskich, Pojezierza Ostródzko-Iławskiego i zlewni rzeki Łyny. Oczyszczalnie różniły się wielkością, udziałem przemysłowych ścieków i technologią odwadniania osadów, z czego wynikały różnice w składzie chemicznym tych odpadów organicznych. W doświadczeniu uprawiano kolejno po sobie (bez przerwy zimowej) pięć roślin warzywnych, jak: seler korzeniowy, sałata, rzodkiewka, burak liściowy i szpinak. Przed założeniem doświadczenia i po zbiorze każdej rośliny badano podstawowe właściwości fizyczne i chemiczne gleby w celu określenia, czy nawożenie osadami ściekowymi może powodować zagrożenie skażenia środowiska glebowego w warunkach uprawy roślin warzywnych. Wykazano, że w większości przypadków zastosowanie osadów ściekowych nie wpłynęło ujemnie na badane parametry gleby. Zawartość węgla organicznego pod wpływem nawożenia osadami w wielu przypadkach wzrosła i nastąpiła poprawa właściwości retencyjnych gleb. Stosowanie osadów ściekowych z Zalewa – ze względu na wysoką zawartość chromu – może spowodować zagrożenie dla środowiska glebowego. W przypadku stosowania doglebowego osadów ze Spychowa, Olsztyna i Olsztynka stwierdzono w glebach ponadnormatywne stężenie cynku.

Słowa kluczowe: : osady ściekowe, oczyszczalnie w północno-wschodniej Polsce, właściwości gleby, metale ciężkie.

INTRODUCTION

Difficulties in sustainable management of sewage sludge in Poland have lead to a series of studies concentrated on presenting available options. Because the European Council recommends recycling as the most desirable solution for management of growing amounts of sewage sludge, this option has been studied most extensively (FILIPEK-MAZUR, GONDEK 2001, JACKOWSKA AND PIOTROWSKI 1995, MAĆKOWIAK 2001, SIUTA 1999).

It has been concluded that, as sewage sludge contains nutrients in the proportions that can satisfy demands of many crops, it can be treated as high value organic amendment. On the other hand, sewage sludge can contain many undesirable and harmful substances such as trace metals, polycyclic organic hydrocarbons, polychlorinated chemicals like PCBs, PCDDs/PCDFs and AOX (BERNACKA, PAWŁOWSKA 2000). These pollutants usually pass intact through the sewage treatment processes and can be accumulated in soil environment after soil application of sewage sludge, which might lead to their transfer to a food chain (BECK et al. 1996, PARKPAIN et al. 2000).

Therefore, it must be stressed that sewage sludge to be applied in agriculture should meet detailed criteria stated by legal regulations. Studies on sewage sludge agricultural utilization in the region of north-eastern Poland, where tourism and agriturism are becoming an important branch of economy, are essential. Besides, the society demands that an environmentally safe alternative for sewage sludge utilization be found. Another factor that must be taken into account is that deposition of sludge on landfills will be banned in 2010 and at present Poland lacks mature technology of sludge incineration. There are many water treatment plants in Poland that have just started operation or gone through modernization, so the amount of sludge they generate is expected to increase considerably in the nearest future. Therefore, finding a sustainable solution for management of growing amounts of sewage sludge is highly desirable.

The study presented in this paper aimed to evaluate the risk of agricultural utilization of sewage sludge originating from north-eastern Poland by performing a model experiment on a pot trial scale.

MATERIAL AND METHODS

Samples of sewage sludge were taken from 19 water treatment plants localized in north-eastern Poland. The treated wastewater from those plants is discharged surface water bodies (lakes and rivers) in the area known as the Green Lungs of Poland, hardly polluted and characterised by high and unique environmental values.

The wastewater treatment plants were divided accordingly:

– ten plants were localized in the Great Masurian Lakes region: Giżycko, Kętrzyn, Mikołajki, Mrągowo, Orzysz, Piecki, Pisz, Ryn, Spychowo and Węgorzewo
– six plants were localized in the Łyna River Basin: Bartoszyce, Biskupiec, Dobre Miasto, Lidzbark Warmiński, Olsztyn and Olsztynek
– three plants were localized in Ostróda and Iława Lake District: Iława, Ostróda and Zalewo.

All the wastewater treatment plants purify sewage waters from relatively small towns (the average population less than 40.000) except the treatment plant in Olsztyn, which receives sewage and wastewater from the regional capital town with a population of 170.000 (Table 1).

Nearly all the wastewater treatment plants treated mainly municipal sewage waters, including a small percentage of industrial effluents (from 0 to 30%), mainly form the dairy, meat or vegetable processing industries. In Mrągowo, 95% of sewage waters came from the dairy industry and in Zalewo – 80% of effluents were from a tannery plant, in which $FeSO_4$ was applied for immobilization of chromium ions.

Differences in technologies for the drying of sewage sludge determine the content of dry matter. Among the nineteen plants we examined, two methods prevailed: filtration press or lagoons. In two plants, Mikołajki and Węgorzewo, reed biofilters were established. The content of dry matter in sewage sludge samples ranged from 10.6% ((Mrągowo) to 33.3% (Biskupiec) – Table. 1.

Basic physical and chemical parameters of soil used in the pot model experiment are given in Tables 2 and 3. Soil reaction was acid and the humus content was very low. The soil was very rich in available phosphorus but poor in potassium and magnesium. None of the trace metals we determined exceeded the permissible levels for agricultural soils (KABATA-PENDIAS, PENDIAS 1999).

The model pot trial was conducted in a greenhouses owned of the University of Warmia and Mazury. The soil samples were placed Kick-Brauckmann plastic pots of the capacity of 10 kg of a growing medium.

The experiment was performed in four replicates and samples of sewage sludge taken from the nineteen sewage treatment plants were applied at the rate of 200 g DM pot^{-1}. Pots without sludge were treated as control.

Before planting the first experimental plant (root celery) mineral nutrients were applied once at the following rates:
– N – 0.35 g · pot^{-1} as $CO(NH_2)_2$,
– P – 0.25 g · pot^{-1} as KH_2PO_4,
– K – 1.54 g · pot^{-1} as K_2SO_4 and KH_2PO_4.

Then the following plants were grown in the this sequence:
– root celery (3 plants · pot^{-1}),
– lettuce cv. Justyna (3 plants · pot^{-1}),
– small radish cv. Agata (5 plants · pot^{-1}),
– Swiss chard cv. Lukullus (5 plants · pot^{-1}),
– spinach cv. Asta (9 plants · pot^{-1}).

The plants selected for the experiment belong to fast growing and high yielding vegetables. During the plant growth, soil humidity was maintained at 60% of water capacity.

In the nineteen wastewater treatment plants, representative samples of sewage sludge were taken and pretreated for laboratory analyses. Samples were air dried at of 22^{o}C and then grounded in a pestle and mortar then with a laboratory mill. The following analyses were performed:
– dry matter content determination,
– pH in H_2O and 1M KCl,
– electroconductivity,
– content of organic carbon by Tiurin method.

In order to determine the trace metals, such as Cd, Pb, Cr, Ni, Cu, Zn, soil samples were digested in a mixture of concentrated acids: HNO_3

Table 1

Characteristics of origin and content of dry matter of sewage sludge samples

Sewage treatment plant	Amount of sewage waters ($m^3 \cdot day^{-1}$)	Kind of effluents	Branch of industry	Per cent of industrial effluents	Method of sludge dewatering	Dry matter (%)	Population $\times 10^3$
Great Masurian Lakes							
Giżycko	7000	municipal/ industrial	dairy	13	press	15.2	25
Kętrzyn	12000	municipal/ industrial	machine, electrical	25	press	14.0	27
Mikołajki	800	municipal/ industrial	food processing	10	press	15.3	8
Mrągowo	1200	municipal/ industrial	dairy	95	lagoon	10.6	0.35
Orzysz	1000	municipal	-	0	press	19.1	4
Piecki	500	municipal	-	0	lagoon	11.5	3.3
Pisz	3000	municipal/ industrial	wood processing	5	lagoon	18.8	20
Ryn	360	municipal	-	0	lagoon	17.1	3
Spychowo	136	municipal	-	0	lagoon	24.3	1.6
Węgorzewo	2270	municipal/ industrial	dairy, meat processing	15	press	11.5	13
Ostróda and Iława Lake District							
Iława	5800	municipal/ industrial	meat processing, machine	10	lagoon	22.2	32
Ostróda	14 000	municipal/ industrial	dairy, meat processing	30	lagoon	20.6	35
Zalewo	122	municipal/ industrial	tannery	80	membrane press	24.3	2
Łyna River Basin							
Bartoszyce	4790	municipal/ industrial	diary	13	press	14.3	28
Biskupiec	2600	municipal/ industrial	food processing	10	lagoon	33.3	11
Dobre Miasto	1500	municipal/ industrial	dairy, machine	12	press	27.4	11
Lidzbark W.	630	municipal	–	0	lagoon	21.4	18
Olsztyn	50000	municipal/ industrial	food processing, rubber	15	lagoon	17.1	165
Olsztynek	500	municipal/ industrial	food processing	30	lagoon	27.5	7

Table 2

Basic physical and chemical parameters of soil sampled before establishing the pot experiment

pH in 1 M KCl	Humus (%)	Hh	S	CEC	V (%)	P_2O_5	K_2O	Mg
		(cmol(+) · kg^{-1} soil)				(mg · 100 g^{-1} soil)		
5.46	0.55	0.97	6.75	7.22	87.00	21.4	5.5	2.1

Table 3

Content of trace metals in soil before establishing the experiment

Total form (mg·kg^{-1})					
Cd	Pb	Cr	Ni	Cu	Zn
0.01	7.86	3.21	1.91	1.77	21.95

and $HClO_4$ (3:1 ration) and the digested samples underwent AAS analyses.

The soil was sampled from each pot at 02–0 cm depth after harvesting each of the tested plants. The soil samples were mixed to form one sample per treatment and then representative samples were taken for the following analyses:
- pH in 1M KCl ;
- hydrolytical acidity (Hh) – by Kappen method;
- basic cations (S) – by Kappen method;
- total sorption capacity (CEC) was calculated;
- electroconductivity;
- content of organic carbon by Tiurin method;
- content of ash and organic matter after ignition at 550°C;
- content of the total form of the following trace metals Cd, Pb, Cr, Ni, Cu, Zn by AAS after digestion of soil in a mixture of HNO_3 and $HClO_4$ (2:1 ratio).

All the results were subjected to ANOVA tests and significance of differences was tested by t-test at $P < 0.05$ or $P < 0.01$.

RESULTS

Most of the sewage sludge sampled from the sewage treatment plants showed neutral or slightly acid reaction, except Zalewo, where basic reaction was observed. It can be concluded that in each case sludge was treated with lime (Table 4). Content of organic carbon in the analysed samples ranged from 20.0 (Olsztyn) to 35.7% (Piecki). Despite this range of values, the mean percentages of the organic carbon content in all the areas analysed were nearly identical. Presence of high concentration of organic mat-

Table 4

Chemical and physical properties of samples of sewage sludge taken from 19 sewage treatment plants

Sewage treatment plant	pH in 1M KCl	Organic carbon (%)	Electroconductivity (µS · cm^{-1})	C:N ratio
Giżycko	6.74	24.2	3012	5.6
Kętrzyn	6.69	24.7	3433	4.7
Mikołajki	6.62	27.3	1566	6.8
Mrągowo	7.02	20.8	2891	4.7
Orzysz	6.40	30.0	1145	6.3
Piecki	6.48	35.7	958	11.6
Pisz	6.63	24.8	1687	5.5
Ryn	6.09	25.8	1596	6.7
Spychowo	6.39	29.5	1807	7.6
Węgorzewo	6.53	26.9	2891	6.0
Mean values	6.56	27.0	2099	6.3
Iława	6.76	27.9	731	6.1
Ostróda	6.14	25.5	1867	6.4
Zalewo	8.06	22.4	2407	8.2
Mean values	6.99	25.3	1669	6.7
Bartoszyce	6.87	26.2	2439	6.4
Biskupiec	6.56	30.6	1684	5.2
Dobre Miasto	6.64	30.5	1867	5.8
Lidzbark W.	6.77	20.2	2620	4.6
Olsztyn	6.55	20.0	904	9.8
Olsztynek	6.17	24.6	1747	7.3
Mean values	6.59	25.4	1877	6.1
$LSD_{0.05}$	n.s.	n.s.	n.s.	–

ter in sewage sludge indicates its high value as organic amendment. The organic matter content in the samples of sludge examined varied within a wide range: from 74.5 (Piecki) to 37.5% (Ostróda). In general, samples of sludge from smaller treatment plants had more organic matter than that from bigger plants, although the differences between the four areas set out for the study were within the experimental error.

Analysing the value of C:N ratio it is worth mentioning that the values of this parameter indicated biological stability of organic matter in most of the samples of sewage sludge. Piecki wasterwater treatment plant differed in this respect as the C:N ratio in its sludge was higher than 10. Sludge salinity can be determined by its electroconductivity, which in our study ranged between 903 and 3433 $\mu S \cdot cm^{-1}$. High salinity of sewage sludge can depress its value as soil amendment and pose environmental problems because of the leaching of some ions to groundwater.

Table 5 presents concentrations of the trace metals in the samples of sewage sludge. The average concentration cadmium, which was 2.34 mg $Cd \cdot kg^{-1}$, appeared to be lower than the maximum permissible level for sludge for agricultural applications (10 mg $Cd \cdot kg^{-1}$). This was true even for the sludge from Ostróda, in which as much as 4.89 $Cd \cdot kg^{-1}$ was found. The same results were obtained for lead, copper and nickel, which occurred in the concentrations lower than permissible levels. The content of zinc in sludge from Spychowo plant was slightly higher than the permissible value (2542 vs. 2500 mg $Zn \cdot kg^{-1}$) while the level of chromium in sludge from Zalewo was 17-fold higher than the level allowed for agricultural application of sludge. The latter finding was attributed to the fact that the sludge in Zalewo originated mainly from a tannery plant, in which chromium salts has been used extensively for many years.

The basic parameters of the sewage sludge samples, presented in Tables 4 and 5, indicated that these organic wastes may be used unconditionally in agriculture and in soil reclamation except sludge from Zalewo due to its contamination with chromium.

As is shown in Table 6, most of the sludge samples had quite good influence on soil acidity during the course of the experiment because after harvesting the last test plant (spinach) the soil treated with the sewage sludge from Mrągowo, Piecki, Zalewo, Dobre Miasta and Lidzbark Warmiński was basic in reaction. It is well known that maintaining higher soil pH can prevent transfer of most of trace metals to plant tissues.

One of the environmental targets of organic waste utilization in agriculture is to enrich soil with stable organic matter. The sewage sludge samples we analysed, when added to soil raised its content of organic carbon. The content of organic carbon in soil determined after harvest of the first tested plant was considerably higher comparing to the untreated control (Table 7). The highest organic carbon content increase was observed after application of sludge from Spychowo.

Table 5

Content of trace metals in samples of sewage sludge taken from 19 sewage treatment plants digested in a mixture of HNO_3 and $HClO_4$ ($mg \cdot kg^{-1}$)

Sewage treatment plant	Cd	Pb	Cu	Zn	Ni	Cr
Great Masurian Lakes						
Giżycko	2.50	28.1	200.7	1560	29.6	61.9
Kętrzyn	1.34	17.5	100.8	655	27.0	52.9
Mikołajki	2.09	22.	92.1	1280	27.1	56.5
Mrągowo	0.79	20.1	25.4	363	7.7	19.1
Orzysz	2.50	25.1	96.8	1200	21.1	44.3
Piecki	2.83	24.3	80.8	1715	14.9	40.6
Pisz	2.12	53.3	90.3	1182	26.2	160.5
Ryn	2.89	27.8	110.1	1810	36.1	87.2
Spychowo	4.08	28.6	115.8	2542	20.0	39.3
Węgorzewo	1.89	32.0	91.7	1317	30.0	134.0
Mean values	2.30	27.9	100.4	1363	24.0	69.6
Ostróda and Iława Lakel District						
Iława	3.06	43.4	118.8	1288	35.9	137.2
Ostróda	4.89	42.4	258.4	1985	49.6	112.8
Zalewo	0.03	2.6	12.6	120	31.0	8748.6
Mean values	2.66	29.5	129.9	1131	38.8	2999.6
Łyna River Basin						
Bartoszyce	1.93	23.4	95.0	1243	30.5	74.6
Biskupiec	2.00	17.7	124.0	1173	30.3	73.1
Dobre Miasto	2.15	24.5	140.6	1535	23.3	67.5
Lidzbark W.	0.80	24.2	31.6	417	21.7	71.6
Olsztyn	3.53	33.4	229.3	2175	38.8	90.6
Olsztynek	3.01	44.2	106.3	1493	36.0	94.6
Mean values	2.24	27.9	121.1	1339	30.1	78.6
$LSD_{0.05}$	n.s.	n.s.	n.s.	n.s.	10.1	n.s.

SE – standard error
$LSD_{0.05}$ – for each area
n.i. – non-significant differences

After harvesting the last tested plant (spinach), owing to the accumulation of organic residues from five vegetable crops, the content of organic carbon was higher for each treatment, including the control, and the beneficial effects of sewage sludge treatments were still visible.

Table 6

Effects of application of sewage sludge on some physicochemical properties of soil (samples taken after spinach harvest)

Sewage treatment plant	pH in 1 M KCl	Organic carbon (%)	Electro conductivity ($\mu S \cdot cm^{-1}$)	CEC ($cmol(+) \cdot kg^{-1}$)
Control	7.18	1.04	38.4	11.4
Great Masurian Lakes				
Giżycko	7.14	1.29	170.4	15.5
Kętrzyn	6.91	1.19	56.3	13.9
Mikołajki	7.11	1.29	46.1	16.0
Mrągowo	7.44	1.11	66.5	19.1
Orzysz	6.91	1.29	40.9	15.8
Piecki	7.38	1.37	81.9	16.5
Pisz	7.08	1.29	37.0	15.2
Ryn	6.98	1.22	87.0	12.1
Spychowo	7.07	1.36	110.0	14.2
Węgorzewo	7.13	1.15	87.0	14.4
Mean value	7.12	1.26	78.3	15.3
Ostróda and Iława Lake District				
Iława	7.30	1.24	41.0	18.0
Ostróda	7.17	1.29	28.2	16.9
Zalewo	7.58	1.11	614.2	18.3
Mean value	7.35	1.21	227.8	17.7
Łyna River Basin				
Bartoszyce	7.04	1.31	51.0	15.8
Biskupiec	7.03	1.39	76.8	15.5
Dobre Miasto	7.33	1.32	51.2	15.3
Lidzbark W.	7.54	1.28	89.6	20.2
Olsztyn	7.09	1.21	64.0	15.7
Olsztynek	7.20	1.34	76.8	14.2
Mean value	7.21	1.31	68.2	16.1

The same trend could be found for CEC values. For this parameter, the highest increase was found in the treatment with sludge from Lidzbark Warmiński versus the control (20.24 and 11.44 cmol(+) · kg^{-1}, respectively). The increase of CEC caused by sewage sludge application can be regarded as an advantage of organic waste utilization. More impor-

Table 7

Effects of application of sewage sludge on some physicochemical properties of soil (samples taken after harvest of root celery)

Sewage treatment plant	pH in 1 M KCl	Organic carbon (%)	Electro conductivity (μS · cm^{-1})	CEC (cmol(+) · kg^{-1})
Control	6.30	0.42	1120	8.2
Great Masurian Lakes				
Giżycko	5.78	0.81	2126	10.7
Kętrzyn	6.28	0.85	1137	12.6
Mikołajki	6.11	0.63	1713	11.6
Mrągowo	7.15	0.65	1230	16.2
Orzysz	6.25	0.77	1093	10.8
Piecki	7.19	0.77	1184	12.7
Pisz	6.38	0.65	1335	11.1
Ryn	6.38	0.79	1163	10.7
Spychowo	6.67	0.92	151	13.8
Węgorzewo	6.06	0.80	2030	10.2
Mean value	6.43	0.76	1397	12.0
Ostróda and Iława Lake District				
Iława	6.95	1.10	1150	15.1
Ostróda	6.66	0.84	1094	12.5
Zalewo	7.50	0.58	2021	16.2
Mean value	7.04	0.84	1422	14.6
Łyna River Basin				
Bartoszyce	6.66	0.73	1132	12.8
Biskupiec	6.70	0.68	1136	12.1
Dobre Miasto	6.54	0.80	1410	10.4
Lidzbark W.	7.19	0.71	1172	16.0
Olsztyn	6.70	0.79	1150	11.4
Olsztynek	6.39	0.76	1120	10.6
Mean value	6.61	0.77	1142	12.2

tantly, this effect was seen during the whole experiment. When soil was amended with sludge from Ryn or Kętrzyn, this increase was small. BERKVIST et al. (2003) showed that effects of sewage sludge application were durable and consisted of improvement of soil retention properties.

It is worth mentioning that high values of soil conductivity noticed after the last harvest (spinach) were considerably reduced comparing to the samples tested after harvesting the first rotation plant (root celery). High values of soil conductivity observed after the first harvest seem to have resulted from the application of mineral fertilizers rather than from sewage sludge amendment, which was suggested by a similar pattern of the decrease in conductivity in the control (Tables 6 and 7).

When considering the content of cadmium in soil, one should remember that KABATA-PENDIAS and PENDIAS (1999) reported a limit for agricultural soil of 1-8 mg $Cd \cdot kg^{-1}$. As can be seen from the data in Tables 8 and 9, the values of cadmium in soil, irrespective of the sludge treatment, were lower 10-fold and over than the limit. BERKVIST et al. (2003) concluded that sewage sludge applications did not pose a serious risk of Cd accumulation in soil.

The same relationships were seen for lead content in soil, as sewage sludge treatments increased the Pb content in soil from 5.40 to 10.54 mg $Pb \cdot kg^{-1}$ whereas the legally permissible lead level in agricultural soil is set at 40 mg $Pb \cdot kg^{-1}$.

Because the tannery plant in Zalewo used chromium compounds, the content of this metal in soil during the whole experiment was above the permissible level of 50 mg $Cr \cdot kg^{-1}$, but in the other sludge treatments this level was higher than 7.29 mg $Cr \cdot kg^{-1}$ of the soil sampled after the first or the last harvests.

The nickel content in agricultural soils according to the Polish norms should not be exceed 20 mg $Ni \cdot kg^{-1}$. In the experimental treatments, the level of this metal was considerably lower and the modifications of its content were very small in the course of the experiment. In some earlier studies conducted by MAZUR et al. (1997), elevated concentrations of nickel were found in sewage sludge from tanneries.

Sewage sludge samples appeared to be a source of copper for vegetable plants and the concentration of this trace metal in soil during our the experiment never exceeded the limit value of 25 mg $Cu \cdot kg^{-1}$. In one case, i.e. sludge from Zalewo wastewater treatment plant, it was lower than for the control. Regarding copper, sewage sludge can be considered as a source of this micronutrient for growing vegetable plants. HANEKLAUS et al. (1999) noticed that agricultural application of sewage sludge from different sewage treatment plants in north-eastern Poland increased the level of copper in soil and in plant tissues. GAMBUŚ et al. (1996) found high variability of chemical composition of sewage sludge from sewage treatment plants in southern Poland and different effects of application of this waste on soil properties.

Table 8

Effects of application of sewage sludge on content of some trace metals in the soil (sampled after root celery harvest)

Sewage treatment plant	Trace metal (mg · kg^{-1})					
	Cd	Pb	Cr	Ni	Cu	Zn
Control	0.03	5.40	5.29	2.96	2.39	35.4
Great Masurian Lakes						
Giżycko	0.07	6.36	3.96	2.59	4.11	43.1
Kętrzyn	0.74	6.69	3.26	2.87	3.33	56.4
Mikołajki	0.07	6.61	7.22	3.66	4.50	61.5
Mrągowo	0.04	6.90	6.64	3.34	4.08	57.4
Orzysz	0.03	8.91	3.79	3.18	3.66	64.1
Piecki	0.06	8.18	3.58	3.00	3.11	78.2
Pisz	0.09	8.65	7.97	3.63	4.81	66.8
Ryn	0.07	9.55	4.27	2.45	4.18	74.0
Spychowo	0.13	8.51	4.61	3.24	5.15	90.1
Węgorzewo	0.05	8.45	6.74	3.45	4.11	62.4
Mean value	0.13	7.88	5.20	3.14	4.10	65.4
Ostróda and Iława Lake District						
Iława	0.10	10.63	4.51	2.97	6.91	66.0
Ostróda	0.09	9.95	3.82	3.47	7.53	76.2
Zalewo	0.05	3.71	210.50	2.55	1.71	43.0
Mean value	0.08	8.10	72.94	2.99	5.38	61.6
Łyna River Basin						
Bartoszyce	0.06	8.73	4.16	3.06	4.22	67.0
Biskupiec	0.07	9.29	4.85	3.67	5.27	60.4
Dobre Miasto	0.05	7.95	3.07	2.81	4.30	75.6
Lidzbark W.	0.02	7.75	2.85	2.42	2.06	61.5
Olsztyn	0.06	10.54	7.96	3.90	8.79	97.7
Olsztynek	0.06	8.79	4.22	9.31	9.98	108.1
Mean value	0.05	8.84	4.52	4.20	5.77	78.4

A different pattern was found for zinc, whose permissible content in agricultural soil is set at 80 mg Zn·kg^{-1}, because in three treatments (Spychowo, Olsztyn and Olsztynek) the soil analysed after harvesting the first plant and in one treatment (Olsztyn), in which soil was sampled

Table 9

Effects of application of sewage sludge on content of some trace metals in the soil (sampled after spinach harvest)

Sewage treatment plant	Trace metal (mg · kg^{-1})					
	Cd	Pb	Cr	Ni	Cu	Zn
Control	0.02	5.86	3.76	3.64	3.78	25.8
Great Masurian Lakes						
Giżycko	0.05	4.20	4.17	3.27	5.27	32.6
Kętrzyn	0.14	6.75	3.84	4.10	5.66	47.3
Mikołajki	0.06	7.44	5.10	4.16	5.58	54.8
Mrągowo	0.03	6.65	6.22	3.14	3.78	61.1
Orzysz	0.17	7.46	4.50	5.52	5.33	60.6
Piecki	0.07	6.86	3.49	4.13	4.56	54.6
Pisz	0.13	8.05	4.86	3.54	4.95	66.8
Ryn	0.06	7.01	2.95	3.27	5.12	68.3
Spychowo	0.36	7.16	3.58	3.46	5.50	54.1
Węgorzewo	0.65	8.64	5.47	3.56	5.49	49.1
Mean value	0.17	7.02	4.42	3.81	5.12	54.9
Ostróda and Iława Lake District						
Iława	0.07	7.35	3.11	4.07	5.35	78.5
Ostróda	0.05	8.05	3.06	4.26	7.47	65.9
Zalewo	0.04	5.25	227.78	3.22	2.93	24.5
Mean value	0.05	6.88	77.98	3.85	5.25	56.3
Łyna River Basin						
Bartoszyce	0.06	13.24	3.17	3.81	5.36	49.7
Biskupiec	0.11	6.74	3.10	3.59	5.14	55.7
Dobre Miasto	0.06	11.19	5.65	3.51	6.50	48.7
Lidzbark W.	0.05	7.62	3.74	4.00	4.07	28.9
Olsztyn	0.07	7.85	7.29	3.52	8.43	89.0
Olsztynek	0.11	7.78	4.98	4.07	5.81	64.7
Mean value	0.08	9.07	4.65	3.75	5.88	56.1

after the harvest of the last plant in rotation, this limit value was exceeded. It is worth noticing that KABATA-PENDIAS and PENDIAS (1999) set this norm at a higher level, i.e. 150-400 mg Zn$\cdot$kg^{-1} and this value was not exceeded in the experiment. BARAN et al. (1996) found that sewage sludge application resulted in increased Pb and Zn content in soil and the content of lead in maize was four-fold higher than in the control.

Generally, if sewage sludge from Zalewo is excluded from agricultural use, the method of soil application of sewage sludge can be acceptable, even if the soil is used for growing vegetable crops, in terms of the status of soil chemical properties and contamination with trace metals is concerned. MAZUR et al. (1997) studied effects of sewage sludge from tanneries and they found that there is a risk of contamination of soil environment.

Environmental threats associated with soil application of sewage sludge from wastewater treatment plants which treat municipal waters can be considered as negligible. Further studies have to be performed concerning effects of sewage sludge application on accumulation of persistent organic pollutants and transfer to a food chain because in some papers such risk has been implied.

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