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Advantages and potential risks of municipal sewage sludge application to urban soil

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ABSTRACT

The aim of this study was to evaluate some advantages and potential risks of application of sewage sludge from the Municipal Wastewater Treatment Plant in Sokółka to urban soils. The sewage sludge used in the research was free of *Salmonella* and viable helminth ova—*Ascaris* sp., *Trichuris* sp., *Toxocara* sp. The study also included the determination of concentrations of Cd, Cr, Cu, Mn, Ni, Pb and Zn in soil and in the aboveground parts of lawn grasses and selected physical and chemical properties of soils fertilized with different doses of sludge. The narrow ratio of carbon to nitrogen on test areas provides conditions for rapid decomposition of the organic matter and may cause a gradual release of metals into the soil solution, thus making them more available to the plants. The bioconcentration factor of heavy metals in the plants along the main streets of Białystok is characterized by considerable local variation. Based on these results, it was found that plants absorbed small amounts of Mn, Ni and Pb, while Zn, Cr, Cu and Cd were easily consumed, which may indicate their high mobility.

Keywords: Sewage sludge; Heavy metals; Lawn grasses

1. Introduction

Many national authorities express an opinion that agricultural use of sewage sludge constitutes the best way for recycling, while incineration is considered the worst, however, other authors have different opinions [1,2]. Recycling of sewage sludge must be performed under some conditions, especially limiting the health risks with pathogens or heavy metals. The four major types of pathogens: bacteria, viruses, protozoa and helminths may be present not only in domestic sewage, but also in sewage sludge. The pathogens in municipal sewage are primarily associated with insoluble solids since wastewater treatment processes concentrate these solids into sewage sludge. As a result, untreated or raw primary sewage sludge has higher quantities of pathogens than the incoming wastewater [3]. The level of parasitological and microbiological contamination of sewage sludge by no

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means depends on the kind of incoming wastewater and a treatment technique applied.

A lot of countries have introduced some legislative acts to control the quality of sewage sludge, but only a few of them have respected microbiological aspects also—for instance, the USA, the Republic of South Africa, Switzerland, France, Austria and Poland [3–5]. The Polish legislation is much more restrictive than the primary piece of legislation on the use of sewage sludge in agriculture in force in the European Union—Council Directive 86/278/EEC of 12 June 1986 [6]. Furthermore, it allows the use of sewage sludge on non-agricultural land and adaptation to specific needs of waste management plans, land use plans or zoning and land use, as well as cultivation of plants for production of compost and crops not intended for human consumption and production of animal feeds [7]. According to the Polish Standards (Dz. U. 2010 Nr 137 poz. 924) [7], the classification of sewage sludge is based on detection of heavy metal contents (Table 1) and biological indicators: pathogenic bacteria from *Salmonella* genus and three of the viable helminth ova—*Ascaris* sp., *Trichuris* sp., *Toxocara* sp. (ATT). If sewage sludge (biosolids) from municipal wastewater treatment fulfils these conditions, it can be applied to agricultural land (cropland), plant nurseries, maintenance of road embankments, re-cultivation, as well as under lawns. As a result of sewage sludge application to soil, in numerous cases, the sanitary risk is still high.

Walking through fields, lawns, or some recreational areas shortly after sewage sludge has been applied, may have a negative impact on one's health due to contact with soil or inhalation of microorganisms spread by strong wind [8]. U.S. Environmental Protection Agency. (1999). Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge, EPA/625/R-92/013, Revised edition, U.S. EPA, Washington, DC.

It is worth emphasizing that usage of dewatered sewage sludge under lawns may cause limitation of sanitary risks connected with its application. In the first period after sowing, the lawn is usually covered with geo fibre, which limits the number of wafting particles including bioaerosols (aerosolized biological ranging from 0.02 to 100 μm). The growth of grass is fast which reduces microbiological contamination emission and the content of heavy metals in soil [9].

The aim of this study was to evaluate the advantages and potential risks of application of municipal sewage sludge from the Municipal Wastewater Treatment Plant in Sokółka to urban soils. The attention was especially focused on heavy metals' concentration (Cd, Cr, Cu, Mn, Ni, Pb and Zn) in soil and in the aboveground parts of lawn grasses.

2. Materials and methods

2.1. The experiment area and sewage sludge application

The study was conducted on four specially prepared test areas along the main streets of Białystok (Hetmańska Str., Piastowska Str., Popiełuszki Str. and Raginisa Str.). Each test area was divided into three

Table 1
Selected properties of municipal sewage sludge from the Municipal Wastewater Treatment Plant in Sokółka

Properties		Maximum levels of heavy metals in municipal sewage sludge for land reclamation for non-agricultural purposes in accordance with regulation [7]
pH	6.7	–
Dry weight (%)	19.3	–
Organic matter (% d.w.)	58.4	–
Total P (% d.w.)	2.7	–
Total N (% d.w.)	4.0	–
Ammonium N (% d.w.)	0.1	–
Ca (% d.w.)	5.5	–
Mg (% d.w.)	0.7	–
Pb (mg kg d.w.$^{-1}$)	23.5	1,000
Cd (mg kg d.w.$^{-1}$)	<0.5	25
Cr (mg kg d.w.$^{-1}$)	58.0	1,000
Cu (mg kg d.w.$^{-1}$)	194.0	1,200
Ni (mg kg d.w.$^{-1}$)	22.0	400
Zn (mg kg d.w.$^{-1}$)	1459.0	3,500

blocks (30 m^2 each) and each of them was divided into six plots of 5 m^2 area. In the fall of 2010, test areas were fertilized with stabilized municipal sewage sludge from the Municipal Wastewater Treatment Plant in Sokółka with three doses 0.0 (control), 7.5 and 15.0 kg/m^2 (sewage sludge containing 19.3% of dry matter). The doses of sewage sludge were established according to Kiryluk [10], who found after several years of study that the most effective doses for turfing of municipal waste disposal areas were those above 40 t/ha. The Municipal Wastewater Treatment Plant in Sokółka treats municipal waste and wastewater of industrial origin, mainly from plants producing dairy products. The system of wastewater treatment is based on the operation on sequencing batch reactor. The capacity is on the level of 6,000 m a day and the produced amount of sewage sludge is estimated at real 330 tons of solid mass a year.

Before the establishment of the experiment both sewage sludge and soil samples from each combination were analysed according to the Directive of Minister of the Environment of 13 July 2010 concerning municipal sewage sludges [7]. The chemical and physical analyses were done by the Regional Chemical and Agricultural Station in Białystok.

2.2. Determination of parasitological tests

The parasitological tests were conducted in accordance with Polish Standard PN-Z-19000-4:2001 and American Tulane Method [11,12]. Dry matter was determined according to Polish Standard PN-EN 12,880:2004 [13]. *Salmonella* tests were carried out in accordance with the method 1,682 recommended by EPA [14]. Additionally, the detection of faecal *coliform* bacteria was done with the method 1,681 recommended by EPA [15].

2.3. Determination of chemical and physical properties of soil

The determination of particle size was done by the Casagrande areometric method modified by Prószyński, which embraces measuring the density of soil suspension during progressive sedimentation of soil particles at a constant temperature. Density measurements were made with the Prószyński hydrometer, and the density of the soil suspension were read in the periods indicated in the tables developed by Prószyński. This procedure is regulated by the PN-R-04032 [16] standard published mostly for agricultural soil analysis. Additionally, two times in season pH of the soil was measured in water and in 1 M KCl.

2.4. The grass mixtures used in the experiment

In the experiment two grass mixtures were used: Eko from Nieznanice Plant Breeding Station which included 30.0% of *Lolium perenne* cv. Niga, 15.0% of *Poa pratensis* cv. Amason, 22.6% of *Festuca rubra* cv. Adio and 32.4% of *Festuca rubra* cv. Nimba. and Roadside from Barenbrug which included 32.0% of *Lolium perenne* cv. Barmedia, 5.0% of *Poa pratensis* cv. Baron, 52.0% of *Festuca rubra rubra* cv. Barustic, 5.0% of *Festuca rubra commutata* cv. Bardiva (BE) and 6.0% of *Festuca rubra commutata* cv. Bardiva (NL).

2.5. Determination of total heavy metals concentrations in soils and plants

In October 2011, samples of soil (0–20 cm) were collected. Concentrations of heavy metals in soils with sewage sludge and in plant material were determined using atomic absorption spectrometry (AAS). The samples of soil were mineralized in temperature at about 450 °C and the remains were dissolved in aqua regia (3:1 mixture HCl and HNO_3) at 80 °C (PN-ISO 11047:2001) [17]. The samples of mixtures of grasses were mineralized at a temperature of about 450 °C and the remains were dissolved in concentrated HNO_3 [18].

Plants for the dry matter determination were taken in September at the end of the growing season, afterwards they were dried in an oven at 105 °C for 24 h, and then at 75 °C until water evaporated completely. Bioconcentration factors (BCFs) for analysed heavy metals were determined as quotients of average concentration of a given element in plants with relation to its average concentration in soil [19].

2.6. Statistical analysis

The correlation between heavy metals' concentration in aboveground parts of plants and in soil fertilized with different doses of sewage sludge were calculated using Pearson's correlation factor *r* for $p \leq 0.05$ by using Statistica 9.0.

3. Results and discussion

Urban soils are exposed to various types of risks in connection with constantly evolving industries and transport and they require remediation treatment. Management of municipal sewage sludge is a very important and still relevant problem due to permanent increase of municipal sewage sludge, the prohibition of storage options after 1st January 2013, as well as some trends towards reducing its use for agricultural purposes [20]. Therefore, the sludge can be a good nutrient base for growing grasses, in particular, for those grown on urban soils [21]. According to Seleiman et al. [22], the sludge for reclamation should be stable and conform to the standards regarding heavy metal content and hygienic sanitary conditions.

In the present research, dewatered sewage sludge from the wastewater treatment plant in Sokółka was used. Prior to sewage sludge application, reference chemical and physical tests of sewage sludge samples and soil samples had been done. The analyses were conducted at the Regional Chemical and Agricultural Station, Białystok. The obtained results are shown in Tables 1 and 2.

According to the Polish regulation, microbiological and parasitological tests of sludge and soil samples were conducted as well and Table 3 presents the results. In accordance with Regulation (2010) for the use of sludge for reclamation of land for non-agricultural purposes, the total number of live eggs of intestinal parasites *Ascaris* sp., *Trichuris* sp., *Toxocara* sp. in 1 kg of sewage sludge dry weight could not exceed 300. In the case of the use of sewage sludge for agricultural purposes and for reclamation of land for agricultural purposes the sewage sludge should be deprived of sediment bacteria of the genus *Salmonella* [7].

In the tested samples, neither *Salmonella* bacteria, nor invasive nematode eggs belonging to the genus *Ascaris*, *Trichuris* and *Toxocara* were found. The examined sediment also met the requirements for physical and chemical parameters. The number of faecal coliform bacilli (faecal coliforms) in the soil was at a low level. The number of faecal coliform bacteria in sewage sludge from municipal wastewater treatment plant in Sokólka was lower than that in the research carried out by Butarewicz [23], where the average number of those bacteria was 7.2×10^5/g dry weight.

The studied dewatered sewage sludge, according to the Polish Standards, could be used as a lawn fertilizer. According to Kalembasa and Malinowska [20], such an organic substance introduced into the contaminated soil may increase the mobility of heavy metals as a result of complexation of the low molecular weight of organic compounds.

Among the physico–chemical properties of the soil, which determine the availability of metals for plants, one can distinguish particle size, pH, organic matter and heavy metals fractionation contents [17]. Soil pH influences an equilibrium of sorption and desorption processes of hydrogen cations and metal cations [24]. The analysis showed a significant inversely proportional correlation with $\alpha < 0.05$ between pH measured in 1 M KCl and copper concentration in the mixtures of grasses collected at Popiełuszki street ($r = -1.0$). In the case of the samples taken at Piastowska street a negative correlation between the content of zinc in the soil and pH KCl ($r = -0.8$) and the copper content in plants ($r = 0.9$) was found (Table 5). Many authors

Table 2
Selected physical and chemical properties of soils at four studied locations

Properties	Hetmańska Str.	Piastowska Str.	Popiełuszki Str.	Raginisa Str.	The limits of heavy metals in the surface of light soil layer (0–25 cm) with the application of municipal sewage sludge for land reclamation for non-agricultural purposes according to Regulation [7]
pH	7.9	7.7	7.6	7.4	–
Sand (%)	75.9	71.9	75.7	84.4	–
Silt (%)	22.0	25.4	22.3	14.7	–
Clay (%)	2.1	2.7	2.0	1.0	–
Textural class	Loamy sand	Sandy loam	Loamy sand	Sand	–
Category soils	Light	Light	Light	Light	
P_2O_5 (mg 100 g^{-1})	7.3	18.4	22.0	10.0	–
Cd (mg kg $d.w.^{-1}$)	< 0.5	<0.5	1.7	<0.5	3
Cr (mg kg $d.w.^{-1}$)	10.9	13.6	13.1	8.3	100
Cu (mg kg $d.w.^{-1}$)	9.5	16.8	17.9	8.8	50
Ni (mg kg $d.w.^{-1}$)	4.5	10.8	5.9	4.6	30
Pb (mg kg $d.w.^{-1}$)	12.4	23.9	26.5	12.1	50
Zn (mg kg $d.w.^{-1}$)	40.9	195.0	82.9	36.6	150

Table 3
Values of studied microbiological and parasitological indicators in sewage sludge samples and soil samples before application of sludge

Designation	The kind of a tested sample				
	Hetmańska Str.	Piastowska Str.	Popiełuszki Str.	Raginisa Str.	Sewage sludge
	The number per kg of DM				
Ascaris sp. *Trichuris* sp. and *Toxocara* sp. (ATT)	0	0	0	0	0
	The number per gram of DM				
Salmonella	0	0	0	0	0
Fecal coliforms	5.5×10^2	2.8×10^3	2.6×10^2	1.5×10^2	3.1×10^5

[24,25] reported that with the increase of pH range (neutral and alkaline), the availability of metals to plants is greatly reduced. According to Benavides et al. [26], soil pH is not constant and changes even within small distances, for example. as a result of intensification of the local rhizosphere microbial activity and root activity. Moreover, it changes regularly during the growing season, it increases in winter and spring, and decreases in summer, during the period of increased activity of micro-organisms which produce acids and roots producing acidic exudates. It was not corroborated by our own research because throughout the growing season soil pH on all the test plots was alkaline and ranged from pH 7.2 to pH 7.8, and the acidity of the replacement of pH from 7.0 to 7.6 (Table 5). Slightly alkaline pH of the soil, which occurred in our experiment in each studied points, may be associated with the presence of debris–limestone additives and the deposition of alkali dust.

Granulometric study for test plots after the application of sewage sludge fertilization showed that the soil in the top layer consists mainly of loamy sand and light loamy sand. Comparing these results with those obtained before the onset of the experiment, it can be seen that the particle size distribution is improved, namely, the percentage of the floatable parts increased at the expense of the sand. The correlation analysis of the result obtained at Raginisa street showed a statistically significant negative correlation between the sand contents in the soil and the content of Zn, Pb, Cu and Ni ($r = -1$, $r = -0.9$, $r = -0.9$ and $r = -1.0$) and a positive correlation between the sand content in the soil and the content of Mn ($r = 0.9$). For this location a significant positive correlation was observed between the clay content in the soil and the concentration of lead and nickel ($r = 0.9$ and $r = 0.8$) (Table 4), which confirms the observations made by Rosada [24]. Positive correlations between the content of clay and manganese in the soil ($r = 0.9$) were obtained for the samples collected at Hetmaniska street. Furthermore, there was a positive correlation between sand content in the soil at Popiełuszki street and zinc content in plants ($r = 0.8$) and between the content of clay in the soil and cadmium in plants ($r = 0.9$).

Another factor limiting the mobility of metals in the soil is their content of organic matter (humus in particular). Sewage sludge fertilization affected the organic carbon content in the topsoil. Humus in the soil acts as a protectant, mainly because it contains humic compounds. Humic substances are characterized by a high content of functional groups such as carboxyl, hydroxyl, amino and others, so in the reactions with metal salts they can form chelate complexes. Such compounds limit the passage of heavy metal ions to the plant root system, and, therefore, their content in the further downstream of the trophic chain is much lower [21,22]. The studies carried out show that soil in urban areas is characterized by a very low content of C organic. The highest average value of organic C (2.9%) was observed at the highest fertilization with sewage sludge (15.0 kg/m^2), while the lowest at 0.0 kg/m^2 approximately 0.6% of the plots in Raginisa street (Table 5). The correlation analysis for the results obtained for Popiełuszki street showed a positive relationship between the content of organic carbon in the soil and in the cadmium concentrations ($r = 0.9$). Furthermore, there was a negative correlation between the content of C_{org} in the soil, and cadmium concentrations in grasses ($r = -0.8$) for Piastowska street. The statistical analysis carried out for the results obtained for Raginisa street showed a positive correlation between the concentrations of C_{org} in the soil and in plants containing zinc, copper and manganese ($r = 0.9$, $r = 0.9$ and $r = 0.8$) (Table 4).

Soils fertilized with sewage sludge and without sludge fertilization were characterized by a narrow ratio of C : N. Under the conditions of application of sewage sludge, the C : N ratio was higher (ranged from 4.8 to 5.9 with 7.5 kg/m^2, and from 4.1 to 7.5

Table 4
Coefficients of correlation between total content of heavy metals in soil and grass mixtures and pH, granulometric parameters, C_{org} and EC at the end of the experiment at Hetmańska Str., Piastowska Str., Popiełuszki Str. and Raginisa Str.

	Soil							Grass mixtures						
	Cd	Zn	Pb	Cu	Cr	Ni	Mn	Cd	Zn	Pb	Cu	Cr	Ni	Mn
	Hetmańska Str.													
pH_{KCl}	−0.4	−0.4	−0.3	0.3	−0.2	−0.1	−0.2	0.2	0.2	−0.2	−0.1	−0.6	−0.5	−0.3
Sand	0.1	0.3	−0.2	−0.3	−0.6	−0.7	−0.7	−0.9	−0.8	0.3	−0.5	0.8	0.2	−0.2
Silt	0.0	−0.4	0.1	0.3	0.5	0.6	0.4	0.9	0.7	−0.6	0.2	−0.7	−0.2	0.0
Clay	−0.2	0.0	0.2	0.3	0.6	0.7	0.9*	0.7	0.8	0.2	0.7	−0.7	−0.2	0.5
C_{org}	−0.4	−0.5	−0.4	−0.5	0.4	0.6	0.4	0.7	0.8	0.0	0.7	−0.5	−0.1	0.8
EC	0.3	0.4	0.4	0.5	−0.3	−0.4	0.1	−0.2	−0.4	0.1	−0.4	−0.1	0.1	−0.6
	Piastowska Str.													
pH_{KCl}	−0.4	−0.8*	−0.1	−0.9	−0.5	−0.6	−0.7	0.0	−0.4	0.6	−0.3	0.2	−0.4	0.7
Sand	0.6	−0.4	−0.3	−0.4	−0.8	−0.2	0.1	−0.1	−0.6	−0.6	−0.7	−0.3	−0.7	−0.3
Silt	−0.7	0.4	0.4	0.4	0.8*	0.2	0.1	−0.2	0.6	0.5	0.5	0.1	0.6	0.1
Clay	−0.3	0.2	0.1	0.3	0.5	0.2	−0.5	0.6	0.5	0.7	0.8	0.7	0.6	0.5
C_{org}	0.0	0.4	0.5	0.3	0.3	0.1	0.6	−0.8*	0.2	−0.3	−0.4	−0.7	−0.3	−0.4
EC	0.6	−0.4	−0.8	−0.3	−0.6	−0.4	0.1	0.1	−0.4	−0.6	−0.4	0.1	−0.3	−0.4
	Popiełuszki Str.													
pH_{KCl}	−0.2	−0.1	0.0	0.1	−0.1	−0.3	0.5	0.6	−0.3	−0.2	−1.0*	0.6	−0.7	−0.7
Sand	0.2	0.5	−0.1	0.4	−0.6	0.4	0.0	0.1	0.8*	−0.1	0.5	−0.3	0.5	0.6
Silt	−0.1	−0.6	0.1	−0.4	0.6	−0.4	−0.2	−0.3	−0.8	0.2	−0.3	0.2	−0.4	−0.6
Clay	−0.4	0.3	−0.3	0.2	−0.2	0.0	0.7	0.9*	−0.2	−0.2	−0.7	0.3	−0.6	−0.2
C_{org}	0.9*	−0.3	−0.2	−0.4	0.2	0.0	0.2	−0.3	0.2	−0.6	0.3	−0.1	−0.3	0.1
EC	0.8*	0.0	0.1	−0.1	0.1	0.3	−0.2	−0.5	0.3	−0.4	0.5	−0.2	0.2	0.2
	Raginisa Str.													
pH_{KCl}	−0.5	−0.7	−0.5	−0.6	−0.2	−0.7	0.7	0.3	−0.5	0.7	−0.8	−0.8	−0.5	−0.4
Sand	−0.6	−1.0*	−0.9*	−0.9*	−0.8	−1.0*	0.9*	−0.1	−0.4	0.4	−0.5	−0.3	−0.7	−0.2
Silt	0.6	1.0*	0.9*	0.9*	0.7	1.0*	−0.9*	0.2	0.5	−0.5	0.6	0.3	0.8*	0.2
Clay	0.3	0.8	0.9*	0.7	0.7	0.8*	−0.9*	−0.2	0.2	0.1	0.0	0.1	0.4	−0.1
C_{org}	0.1	0.6	0.2	0.7	0.1	0.5	−0.3	0.2	0.9*	−0.6	0.9*	0.2	0.7	0.8*
EC	0.1	0.6	0.3	0.5	−0.1	0.5	−0.4	−0.2	0.9*	−0.6	0.8	0.6	0.5	0.7

*Significant correlations for $p < 0.05$.

Table 5
Selected physical and chemical properties of soils fertilized with different doses of sludge

Street	Dose of sewage sludge (kg/m^2)	pH		Sand (%)	Silt (%)	Clay (%)	C_{org} (%)	C:N
		KCl	H_2O					
Hetmańska	0.0	7.3	7.7	65.5	23.5	11.0	1.4	5.6
	7.5	7.4	7.8	65.5	24.5	10.0	1.7	4.8
	15.0	7.3	7.6	60.5	28.0	11.5	1.9	6.1
Piastowska	0.0	7.3	7.5	51.5	34.5	14.0	2.0	4.4
	7.5	7.2	7.4	46.5	38.5	15.0	2.0	5.4
	15.0	7.0	7.4	53.5	35.0	11.5	2.2	5.5
Popiełuszki	0.0	7.5	7.6	56.0	31.5	12.5	1.2	3.7
	7.5	7.3	7.5	58.0	31.0	11.0	2.0	5.9
	15.0	7.2	7.4	60.5	28.5	11.0	1.5	4.1
Raginisa	0.0	7.6	7.8	76.0	17.5	6.5	0.6	1.7
	7.5	7.5	7.6	66.5	24.0	9.5	1.6	5.8
	15.0	7.3	7.2	65.0	26.5	8.5	2.9	7.5

with 15 kg/m^2) than in the plots in which no sludge was used (Table 5).

BCF allowed to estimate the ability of plants to collect heavy metals present in the soil, and reflected the speed and volume of movement of metals from the soil solution with the addition of different doses of sewage sludge to the aerial parts of plants (Fig. 1).

According to Eapen and D'Souza [27], each metal has a specific pattern of uptake, transport and storage in the plant, and in the presence of other ions in the soil one can observe interactions between the ions. Based on these results, it was found that plants absorbed small amounts of Mn, Ni and Pb, while Zn, Cr, Cu and Cd were easily consumed by the plants, which may indicate their high mobility in comparison with other metals. According to Hassan and Aarts [28], Cd, Zn and Cu accumulate easily in plant tissues, and in this way they enter the food chain.

Drążkiewicz et al. [29] indicate that the rate of bioconcentration of various heavy metals, especially cadmium is characterized by high diversity among species and even cultivars. Although cadmium is not required for plant growth, it is taken very easily [30]. In the case of cadmium bioconcentration the highest rate was observed in the plots located at Hetmańska street where the highestsewage sludge dose was used with grass mixture Roadside and in Piastowska street at fertilization 7.5 kg/m^2 with grass mixture Eko that amounted to 2.0 and 1.9, respectively. According to Rascio and Navari-Izzo [31], uptake of most of the metals by plants depends on the plant variety and species, as well as on the other metal contents in the soil, the type and amount of applied fertilizers and microbial activity of rhizosphere. Moreover, it was observed that the BCF is affected by plot location. The lowest rates of bioaccumulation for all analysed metals have been observed on plants at Popiełuszki street, while the highest rate was observed in the plots located at Hetmańska and Raginisa street (Fig. 1). According to Sutherland et al. [32], road transport is one of the main sources of emissions of pollutants to air and soil in cities, strongly influencing natural environment as a whole and having a negative influence on man.

Copper is of utmost importance for life of all plants. Copper is essential for photosynthesis and mitochondrial respiration, for carbon and nitrogen metabolism and for oxidative stress protection. Therefore, immediately after uptake the vast majority of copper ions is bound by scavenging proteins like metallothioneins to prevent copper from accumulating in a toxic form. However, part of the imported copper bypasses this system and becomes captured by small binding proteins, the so-called copper chaperones [33,34]. According to Lequeux et al. [35], copper is the least mobile element in the plant and most of it after absorption is kept in roots causing some damage to cell membranes, a change of their liquidity and their semi-permeable features, which in the first stage, is seen as the leakage of cell electrolytes from the cells, among others potassium ions, and in the end leads to the disturbance of the whole cell metabolism. Bioconcentration of copper in our study was at a similar level (BCF = 0.5) for almost all the studied locations. Only on the plots located at Hetmańska and Piastowska street BCF was higher and amounted to about 1.0 at a dose of 0.0 and 15.0 kg/m^2 for grass mixture Roadside, and for grass mixture Eko at a sludge dosage of 7.5 kg/m^2.

Zinc is an essential metal for proper growth and development of plants, since it is a constituent of many enzymes. However, excessive concentrations of

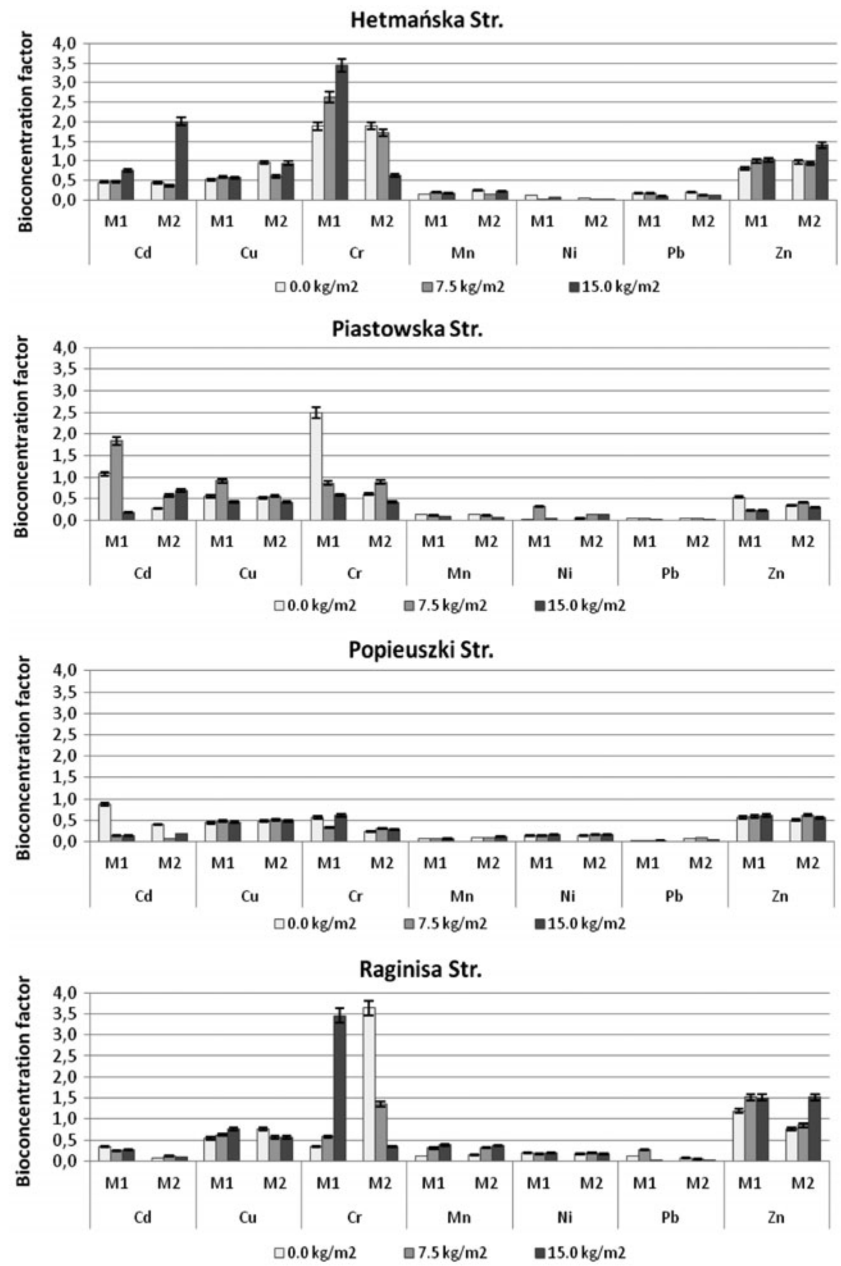

Fig. 1. BCF of heavy metals (Cd, Cu, Cr, Mn, Ni, Pb and Zn) in lawn grassmixtures (M1—Eko, M2—Roadside).

this metal are well known to be toxic to most living organisms. Elevated concentrations of Zn exist in many agricultural soils from management practices, including application of sewage sludge or animal manure and from mining activities, may pose a risk to the environment [36]. The highest rate of zinc bioconcentration was observed on plots located at Hetmańska and Raginisa streets. With increasing fertilizing plots, the BCF increased at the highest doses of sludge for both the analysed grass mixtures and it was about 1.5 for both Raginisa and Hetmańska streets in the latter plot and only with grass mixtures Roadside. According to Wang et al. [37], zinc accumulation at supra-optimal concentrations may delay or diminish the growth and root development and cause leaf chlorosis of Zn-exposed plants. Similar to Cd, Zn excess could cause the formation of reactive oxygen species in the plant cell, which results in cellular oxidative damage and membrane lipid peroxidation in plant cells [38].

Table 6
Coefficients of correlation between the total content of heavy metals in soil and plants

		Total heavy metal contents in grass mixtures						
Location	Total heavy metal content in soil	Cd	Cr	Cu	Mn	Ni	Pb	Zn
Hetmańska Str.	Cd	−0.1	0.2	−0.6	−0.5	0.9*	0.1	−0.5
	Cr	0.5	−0.1	0.7	0.5	−0.4	−0.3	0.7
	Cu	−0.1	0.2	0.2	−0.2	−0.6	−0.3	0.1
	Mn	0.5	−0.4	0.6	0.5	0.3	0.4	0.6
	Ni	0.6	−0.3	0.9*	0.7	−0.5	−0.2	0.9*
	Pb	−0.1	0.2	−0.2	−0.3	0.6	0.2	−0.3
	Zn	−0.5	0.4	−0.2	−0.1	0.6	0.7	−0.5
Piastowska Str.	Cd	0.3	0.3	0.1	0.0	−0.2	−0.2	0.2
	Cr	−0.6	0.2	0.6	−0.1	0.7	0.3	0.9*
	Cu	0.3	0.2	0.7	−0.3	0.7	−0.1	0.8
	Mn	−0.4	−0.6	−0.2	−0.9	0.2	−0.8	−0.1
	Ni	0.2	−0.2	0.4	−0.5	0.5	−0.4	0.2
	Pb	−0.5	−0.4	−0.1	0.4	−0.2	0.4	0.3
	Zn	0.1	0.1	0.6	−0.2	0.6	−0.1	0.8
Popiełuszki Str.	Cd	0.0	0.1	0.0	0.0	−0.2	−0.2	0.2
	Cr	−0.5	−0.6	0.3	−0.1	0.7	0.3	0.9*
	Cu	0.5	0.3	−0.3	−0.3	0.7	−0.1	0.8
	Mn	0.8*	0.3	−0.6	−0.9*	0.2	−0.8	−0.1
	Ni	0.2	−0.5	0.2	−0.5	0.5	−0.4	0.2
	Pb	−0.3	0.6	−0.2	0.4	−0.2	0.4	0.3
	Zn	0.6	−0.2	−0.1	−0.2	0.6	−0.1	0.8
Raginisa Str.	Cd	0.3	0.3	0.4	−0.3	0.6	−0.6	−0.2
	Cr	0.3	−0.2	0.1	−0.2	0.6	0.0	−0.1
	Cu	0.4	0.1	0.6	0.3	0.9*	−0.5	0.5
	Mn	0.1	−0.4	−0.3	0.1	−0.5	0.3	−0.1
	Ni	0.1	0.3	0.5	0.2	0.8	−0.4	0.4
	Pb	0.1	0.2	0.2	−0.1	0.6	−0.2	0.1
	Zn	0.2	0.2	0.6	0.2	0.8*	−0.4	0.5

*Significant correlations for $p < 0.05$.

Cr bioconcentration ratio was 3:4 in the plants with the highest fertilization with sewage sludge used in the research section located at Raginisa street and Hetmańska street in the mixture Eko, but an inverse relationship was observed for the mixture Roadside, and the highest rate of bioconcentration of Cr was on plots without sludge which amounted to 1.9 and 3.6 for Hetmańska and Raginisa streets and with increasing doses of sludge Cr concentration decreased. Its complex electronic chemistry has been a major hurdle in unravelling its toxicity mechanism in plants. The impact of Cr contamination in the physiology of plants depends on the metal speciation, which is responsible for its mobilization, subsequent uptake and resultant toxicity in the plant system. Cr toxicity in plants is observed at multiple levels, from reduced yield, through effects on leaf and root growth, to inhibition of enzymatic activities and mutagenesis. The accumulation of other metals, Pb, Mn and Ni, in plants was the same irrespective of the location of the plots and sewage sludge fertilization (Fig. 1). Heavy metals present in the sludge which are strongly absorbed by the matrix biowaste and added to the soil are less accessible than the ones added in the form of inorganic salts. In fact, sludge added to the soil can even be used as a metal absorber from soil solution [39], as it was confirmed by our own research.

There were significant correlations between concentrations of metals in soil and the metal content in the aerial parts of lawn grass mixtures (Table 6). The results for Hetmańska street showed positive correlations between the content of cadmium in soil and nickel in plants ($r = 0.9$), and nickel in soil and copper and zinc in plants ($r = 0.9$). In the case of Piastowska street one could observe a significant correlation between the content of chromium in the soil and zinc ($r = 0.9$) contained in plants, manganese in the soil and zinc in plants ($r = 0.9$). For Popiełuszki street there was a significant correlation between chromium in soil and zinc in plants ($r = 0.9$), and manganese in the soil and cadmium and manganese in plants ($r = 0.8$ and $r = -0.9$). In turn, for Raginisa street a positive correlation was between the soil copper content and nickel in plants ($r = 0.9$), and the zinc soil content and nickel in the plants ($r = 0.8$).

4. Conclusions

(1) The examined sewage sludge from the municipal wastewater treatment plant in Sokółka did not contain bacteria of the genus *Salmonella* and the viable helminth ova—*Ascaris sp, Trichuris sp, Toxocara*, and it met Polish standards concerning the acceptable content for heavy metals.

(2) The soil on each testing plots was alkaline, which limited, in particular, the uptake of copper and nickel through the grass mixtures, as it is confirmed by the negative correlation coefficients.

(3) Sewage sludge application in the soil influences significantly the content of organic carbon in the soil, which may have contributed mainly to lead, chromium and nickel immobilization, and thus reducing their uptake by plants.

(4) Narrow ratio of carbon to nitrogen provided favourable conditions for rapid decomposition of the organic matter and could cause a gradual release of metals into the soil solution, thus making them more available to the plants.

(5) The highest metal accumulation in plants was in the case of Cr, Zn, Cu and Cd and the remaining metals such as Mn, Ni and Pb accumulated in smaller amounts in the aerial parts.

(6) The BCF of heavy metals in plants along the main streets of Białystok is characterized by considerable local variation.

(7) Based on the results of our work, we recommend the use of sewage sludge as fertilizer in urban soils which require remediation treatments due to the fast advancing degree of degradation.

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