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CONTENT OF CADMIUM IN MAIZE (*ZEA MAYS* L.) AND SOILS FERTILIZED WITH SEWAGE SLUDGES AND MIXTURES OF SEWAGE SLUDGE AND PEAT

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Key words: cadmium, sewage sludge, maize.

Abstract

The investigations aimed at an assessment of treatment with sewage sludges and mixtures of sewage sludge and peat effect on cadmium content in maize and soils with diversified texture. The research was conducted in conditions of pot experiment. Fertilization with sewage sludge and sludge mixtures with peat had a more beneficial effect on maize yields than treatment with mineral salts. As compared to fertilization with mineral salts, organic fertilizers applied to the soil did not increase cadmium concentrations in maize biomass. Soil pH affected cadmium mobility more than applied sewage sludge. Mixtures of sewage sludge and peat (in comparison to sewage sludge as such) slightly better influenced maize biomass yield and had a comparably cadmium content in plant biomass.

ZAWARTOŚĆ KADMU W KUKURYDZY (*ZEA MAYS* L.) I W GLEBACH NAWOŻONYCH OSADAMI ŚCIEKOWYMI I MIESZANINAMI OSADÓW ŚCIEKOWYCH I TORFU

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Słowa kluczowe: kadm, osady ściekowe, kukurydza.

Abstrakt

Celem badań była ocena wpływu nawożenia osadami ściekowymi oraz mieszaninami osadów ściekowych i torfu na zawartość kadmu w kukurydzy i w glebach o zróżnicowanym składzie granulometrycznym. Badania przeprowadzono w warunkach doświadczenia wazonowego. Nawożenie

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osadami ściekowymi i mieszaninami osadów z torfem działało korzystniej na plony kukurydzy niż nawożenie solami mineralnymi. Zastosowane doglebowo materiały organiczne w porównaniu z nawożeniem solami mineralnymi nie zwiększyły zawartość kadmu w biomasie kukurydzy. Większy wpływ na mobilność kadmu wywierał odczyn gleb niż zastosowane osady ściekowe. Mieszaniny osadów ściekowych z torfem (w porównaniu z samymi osadami ściekowymi) działały nieznacznie korzystniej na plon biomasy kukurydzy oraz porównywalnie na zawartość kadmu w biomasie roślin.

Introduction

Progressing economic and civilization development leads to generation of larger amount of sewage and in consequence sewage sludges. Still insufficient utilization of the materials necessitates their storage, which not only incurs considerable costs for the sludge generator but is also only temporary solution to this problem.

Environmental application of sewage sludge is often reduced by microbiological factor but also by its high heavy metal concentrations posing hazards to the cleanliness of the soil environment and crop quality (Sommers 1977, Smith 1994).

Transformations of bioavailability of heavy metals supplied to the soil with sewage sludge are conditioned by the soil properties (Haghiri 1974, Dijkshorn et al. 1981, McGrath, Lane 1989, Bhogal et al. 2003, Holm et al. 2003, Qureshi et al. 2004) and by the properties of each element (Berti, Jacobs 1996), which apparently makes difficult prediction of heavy metal migration from soil to plants (Basta et al. 2005). Therefore, the investigations were undertaken to assess the effect of fertilization with sewage sludge on cadmium concentrations in maize cultivated in soils with diversified texture.

Material and Methods

The assessment of fertilization effect on cadmium concentrations in maize was made in a pot experiment conducted in 2003–2005. The experimental design comprised the following treatments in four replications on three soils: control (0); mineral treatment – (NPK); farmyard manure – (FYM); sewage sludge *A* – (SSA); sewage sludge *B* – (SSB) and mixtures of the sewage sludges with peat (MSSA, MSSB). The soil material used for the experiment comprised: weakly loamy sand (GI), sandy silt loam (GII) and medium silt loam (GIII), collected from the arable layer (0–20 cm) of ploughlands from the Krakow neighbourhood. The sewage sludge used for the experiment originated from two different mechanical-biological municipal sewage treatment plants. Sewage sludges were mixed with peat in the 1 : 1 weight ratio in conversion to material dry mass. The peat containing 408 g kg^{-1} dry matter was characterized by the contents of 88 g kg^{-1} of ash, 34.4 g N, 0.91 g P, 1.14 g K and 0.56 mg Cd kg^{-1} d.m. The characteristics of the chemical composition of the soil material and organic materials were given in Table 1 and Table 2 (values converted into dry matter determined at 105°C).

Table 1

Chemical composition of materials used in experiment

Determination		FYM	Sewage sludge (SSA)	Sewage sludge + peat (MSSA)	Sewage sludge (SSA)	Sewage sludge + peat (MSSB)
Dry matter g kg^{-1}		189	310	343	418	372
pH (H_2O)		6.22	6.12	5.57	5.73	5.20
Organic matter g kg^{-1} d.m.		679	353	652	552	771
Total forms						
N	g kg^{-1} d.m.	21.6	17.0	24.7	37.4	35.1
P		22.60	5.48	3.00	19.32	7.64
K		26.69	2.71	1.88	2.81	1.64
Cd	mg kg^{-1} d.m.	1.28	2.71	1.45	2.25	1.03

Table 2

Some properties of soils before the establishment of the experiment

Determination			Soil		
			(GI)	(GII)	(GIII)
Granulometric composition Ø	1.0–0.1 mm	%	78	42	28
	0.1–0.02 mm		13	33	29
	< 0.02 mm		9	25	43
pH KCl			6.21	5.69	5.30
Hydrolitic acidity		mmol(+) kg^{-1} d.m.	11.2	23.4	33.2
Sum of alkaline cation			39.9	86.8	128.4
Total N		g kg^{-1} d.m.	0.96	1.25	1.72
Organic C			9.37	13.36	17.68
Total S			0.16	0.28	0.32
Total Cd		mg kg^{-1} d.m	0.68	0.65	0.78
Available forms					
P		mg kg^{-1} d.m.	79	217	29
K			166	359	138
Mg			134	154	126
S-SO_4			13.4	11.9	11.4

PVC pots used for the experiment contained 5.50 kg of air-dried soil material. The soils were gradually moistened prior to the experiment outset to obtain 30% of maximum water capacity. After this period sandy silt loam and medium silt loam were limed to obtain pH stated by the decree. The measure was applied separately in each pot. Chemically pure CaO was used in a dose calculated on the basis of soil hydrolytic acidity. Subsequently all soils were left for 4 weeks and water loses were supplemented occasionally. After this period fertilization in organic form was introduced in the amount corresponding to 1.20 g N pot^{-1} . Phosphorus and potassium quantities were supplemented with solutions of chemically pure salts [P – $Ca(H_2PO_4)_2$ H_2O and K – KCl] to equalize the amounts of these components supplied with the organic materials. The identical nitrogen, phosphorus and potassium doses were used on mineral (NPK) treatment as on the treatments receiving organic materials. Doses of N, P and K were, respectively: 1.20 g N pot^{-1} as NH_4NO_3, 1.26 g P pot^{-1} as $Ca(H_2PO_4)_2$ H_2O and 1.48 g K pot^{-1} as KCl. Taking into consideration the residual fertilizer effect and the soils abundance in bioavailable phosphorus and potassium, in the second and third year of the experiment, the following doses of fertilizer components were applied corresponding to: 0.80 g N; 0.2 g P and 1.40 g K pot^{-1} · year^{-1} as chemically pure salts.

Maize, San c.v. (FAO 240) was cultivated each year and 5 plants were left per pot. Maize was always harvested at the stage of 7–9 leaves. Plant growing period in the subsequent years was as follows: 47 days in the first year, 66 days in the second and 54 days in the third. The plants were watered with distilled water throughout the experiment to 50% of the maximum soil water capacity. After the harvest the plants were dried (at 70°C) to constant weight and the yield of dry mass of shoots and roots was determined. Subsequently, the dried biomass was crushed in a laboratory mill and mineralized in a muffle furnace (at 450°C for 5 hours). The remains were dissolved in diluted nitric acid 1:2 (v/v) (OSTROWSKA et al. 1991). The soil material collected each year after completed vegetation period was analyzed with reference to the changes of physicochemical properties occurring in result of the applied fertilization. Cadmium concentrations were determined in dried material sifted through a sieve with 1 mm mesh after extraction with 1 mol dm^{-3} NH_4NO_3 solution (DEL CASTHILO, RIX 1992). Cadmium was assayed in the obtained solutions of plant material and soil extracts using ICP-AES method on JY 238 Ultrace apparatus (France). Plant reference material – NCS DC73348 (China National Analysis Center for Iron & Steel) and soil reference – AG-2 (*Agro*MAT) was added to each analyzed series. The results were elaborated according to a fixed model where fertilization or soil was the factor. Statistical computations were made using single factor ANOVA and the significance of differences were estimated by NIR Fisher test at the significance level $p < 0.05$ (STANISZ 1998).

Results and Discussion

Average yields of maize biomass (the aboveground parts and roots) from treatments obtained over the three-year period on the soil, which belonged to light soil class GI were markedly smaller (by over 20% – irrespectively of the plant part) than the yields from the other two, heavier soils GII and GIII (Figure 1). The difference in yield obtained on sandy loam and medium loam was not significant for the aboveground parts, whereas an average root biomass yield did not differ at all between these two soils.

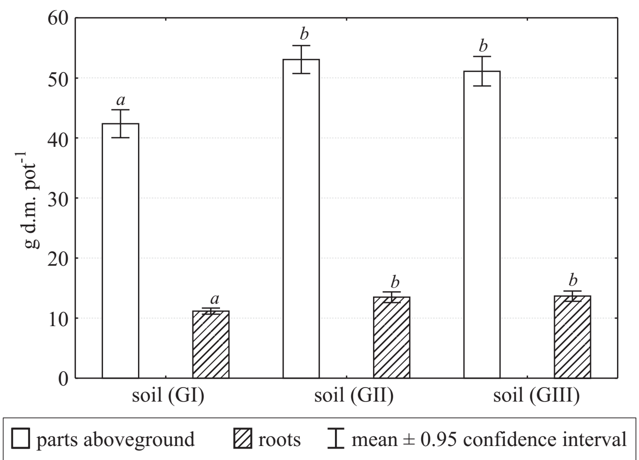

Fig. 1. Mean yields of parts aboveground and roots of maize from fertilization objects from period 3 of years
Means followed by the same letters did not differ significantly at $p < 0.05$ according to the Fisher test

Analysis of variance confirmed an advantageous effect of organic treatment on maize biomass yield (Table 3). Fertilization with sewage sludge or its mixtures with peat and farmyard manure allowed to obtain significantly larger yield than harvested on the object fertilized exclusively with mineral compounds. In both cases when mixtures of sewage sludge and peat were used, larger yield was produced than on the sludge used separately. Fertilizer effectiveness of organic materials is determined mainly by nitrogen content, particularly its mineral forms (SZULC et al. 2004). Nitrogen in the first place determines the amount of obtained biomass yield. However, disturbed relationships between other nutrients may directly affect plant mineral economy. Fertilization with organic materials applied over the three-year period of investigations produced better results visible as the amount of biomass yields, than mineral salt treatment. This effect cannot be fully ascribed to the activity of applied sewage sludge or its mixtures with peat. It resulted from the consequent effect of organic materials and supplementary treatment with mineral salts used in the second and third year of investigations. The factor determining plant yielding might have been also introducing to the soil of other components of organic materials such as sulphur, magnesium or microelements, whose amounts were not balanced. According to WOŁOSZYK (2003), application of natural or organic fertilizers not always causes increase in crop yield in result of so called consequent effect. Research conducted by DRAB and DERENGOWSKA (2003) demonstrated a positive effect of sewage sludge on plat yielding, at the same time revealing that the amount of yield, irrespective of soil is conditioned by the sewage sludge dose. WIATER et al (2004) reported worse direct effect of sewage sludge granulate on maize yield than mineral treatment but the consequent effect of granulate activity was better.

Irrespective of applied fertilization or soil, higher cadmium concentrations were assessed in maize roots (Table 3, Figure 2). The greatest amounts of cadmium were determined in the biomass of aboveground parts and roots of plants from mineral salt treatment. Mean cadmium concentration in biomass for the three years on this treatment was 0.84 mg Cd kg^{-1} d.m. in the aboveground parts and was by over 100% higher than the content assessed in the aboveground parts of maize fertilized with organic materials. Assuming a permissible cadmium content in biomass of plants for fodder on the level of 0.5 mg Cd kg^{-1} d.m., it may be seen that except the biomass from mineral salt treatment, this element concentrations in the aboveground parts did not limit its usability for fodder (KABATA-PENDIAS et al. 1993). Smaller diversification between the treatments was registered for cadmium concentrations in maize root biomass. Significant diversification was registered in maize biomass cadmium concentrations depending on soil (Figure 2). In medium silt loam GIII cadmium content was the largest in the aboveground parts, while in weakly loamy sand GI it was the highest in roots. Results of analyses conducted by PIOTROWSKA and GAŁCZYŃSKA (1990) and PATORCZYK-PYTLIK (2001) reveal that excessive heavy metal accumulation in plants, including cadmium, occurs when large doses of sewage sludge heavily loaded with these elements are supplied with fertilizers. According to WOŁOSZYK (2003) application of moderate doses of sewage sludge does not cause excessive cumulation of heavy metals in plants. Author's own research revealed that significantly greatest quantities of cadmium, irrespective of maize parts, were found in plants fertilized with mineral salts. Presented results corroborate with these published by LOGAN and CHANEY (1983). According to CHANEY (1982) cadmium is the element which is not affected by so called soil-plant barriers, which means that plants tolerate in their organisms (without any toxicity symptoms) the amounts of cadmium which are normally toxic for animals consuming these plants. The above-mentioned statement explains why no decline in plant yield was noted on mineral salt treatment where this element content was the highest. On the other hand KABATA-PENDIAS and PENDIAS (1999) claim that at its increased uptake cadmium mostly accumulates in roots. It most probably results from plant, particularly the unicotyledonous, ability to complex among others cadmium in their roots (INOUHE et al. 1994).

Table 3

3-year period mean yields of dry mass of parts aboveground and roots plants of total cadmium content in maize and mobile forms cadmium in soils

Fertilization	Yield of biomass g d.m. pot^{-1}		Cadmium in the plant g Cd kg^{-1} d.m.		Cadmium in the soil mg Cd kg^{-1} d.m.
	(PAG)	(K)	(PAG)	(K)	
Control (0)	22.1^{a}	7.4^{a}	0.19^{a}	1.47^{ab}	0.024^{b}
NPK	42.5^{b}	10.1^{b}	0.84^{d}	2.43^{c}	0.031^{c}
FYM	48.0^{c}	13.1^{cd}	0.30^{ab}	1.22^{a}	0.018^{a}
Sewage sludge A (SSA)	47.3^{bc}	11.8^{c}	0.42^{bc}	1.67^{ab}	0.020^{ab}
Sewage sludge A + peat (MSSA)	49.3^{c}	11.8^{c}	0.46^{c}	1.72^{b}	0.021^{ab}
Sewage sludge B (SSB)	50.4^{c}	14.1^{d}	0.37^{bc}	1.49^{ab}	0.022^{ab}
Sewage sludge B + peat (MSSB)	55.6^{d}	15.8^{e}	0.36^{bc}	1.57^{ab}	0.023^{b}

(PAG) parts aboveground; (K) roots
Means followed by the same letters in columns did not differ significantly at $p < 0.05$ according to the Fisher test

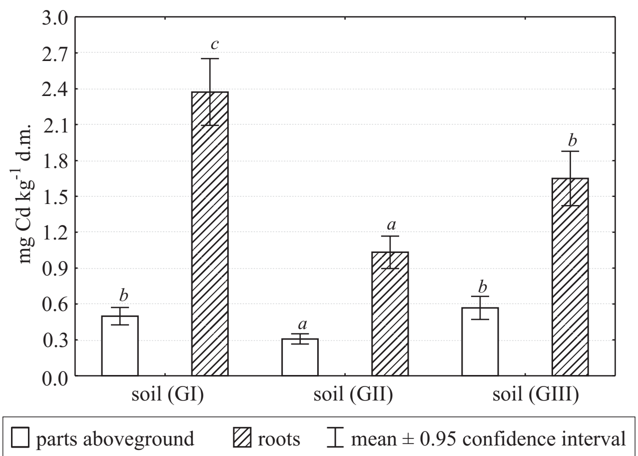

Fig. 2. Mean content of cadmium in parts aboveground and roots maize from fertilization objects from period 3 of years
Means followed by the same letters did not differ significantly at $p < 0.05$ according to the Fisher test

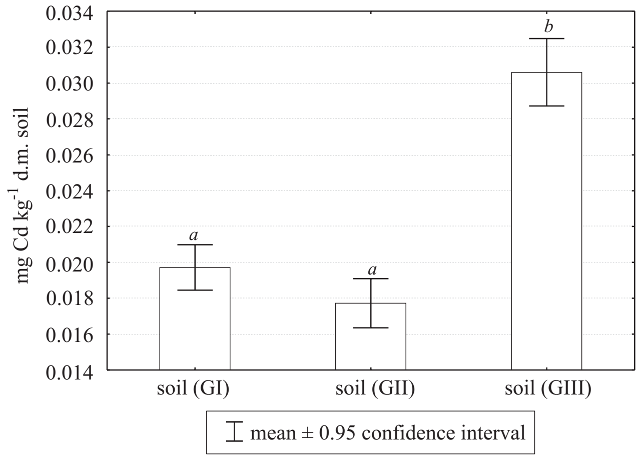

Fig. 3. Mean content of mobile forms of cadmium in soils from fertilization objects from period 3 of years
Means followed by the same letters did not differ significantly at $p < 0.05$ according to the Fisher test

Mean content of mobile cadmium forms in soil after the experiment completion was the greatest in the treatment of the heaviest texture GIII (Figure 3). The conducted research showed that on average the content of this element mobile forms in soils after the application of organic materials was significantly smaller than the concentrations assessed in soils of mineral salt treatments (NPK) – Table 3. It should be emphasized that mean content of cadmium mobile forms in soils from the treatments where organic materials were used was almost the same, whereas soil pH significantly affected this element mobility (SUKREEYAPONGSE et al. 2002) – Figure 4. Heavy metal bioavailability in soils is different for various elements. Heavy metal passing into the soil solution depends on the soil properties and the element itself (BASTA et al. 2005). Presented research revealed progressing soil acidification, especially in result of mineral salt application, irrespective on soil agronomic category, which undoubtedly had a strong influence on improving cadmium bioavailability (WILLIAMS et al. 1987, NARWAL et al. 1983, GONDEK 2008). The results obtained by the Author do not correspond with the results of PATORCZYK-PYTLIK (2001) who does not associate the changes of solubility of among others cadmium compounds in soil with the soil pH, which, according to the quoted author, did not change much after the application of either crude or composted sewage sludge.

In Figures 5–7 placed changes of dry weight yield, its cadmium concentrations and this element mobile forms in soil for the individual years of the experiment. Presented results point to a comparable effect of sewage sludge treatment on cadmium content in maize biomass and the content of mobile

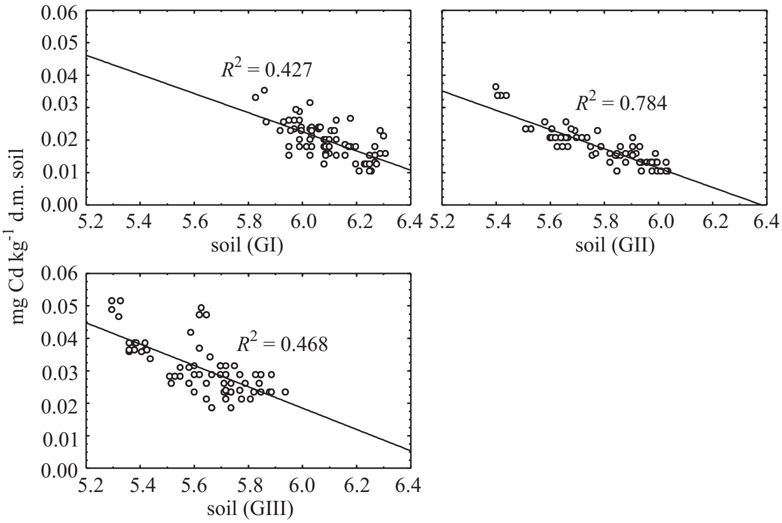

Fig. 4. Relationship between soil pH and mobile forms cadmium content in soil

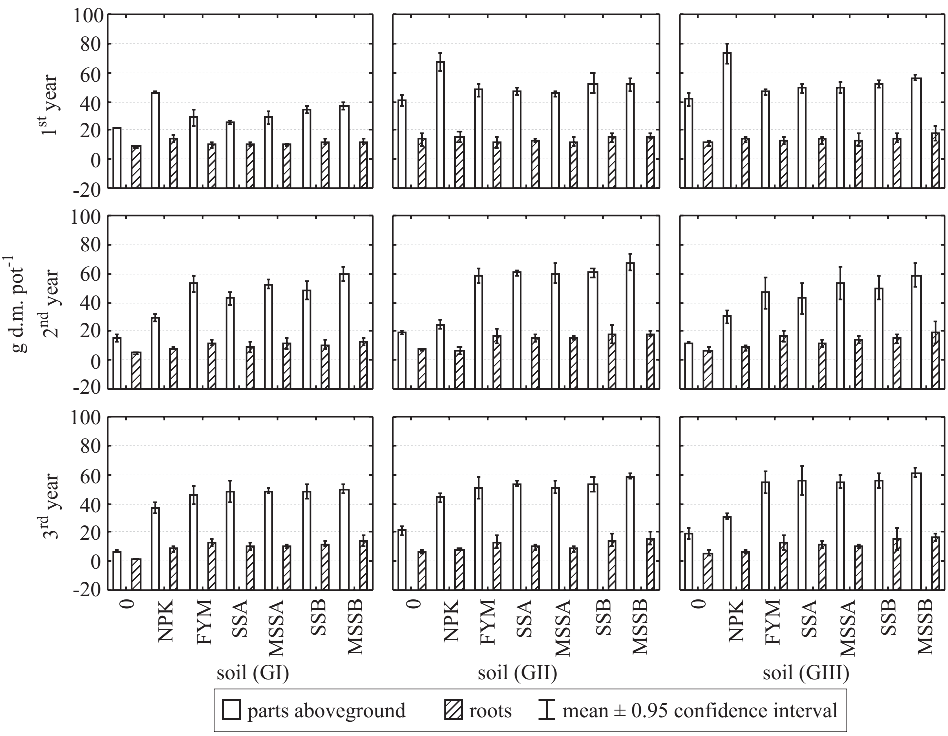

Fig. 5. Yield of parts aboveground and roots of maize from three years of the experiment on three soils

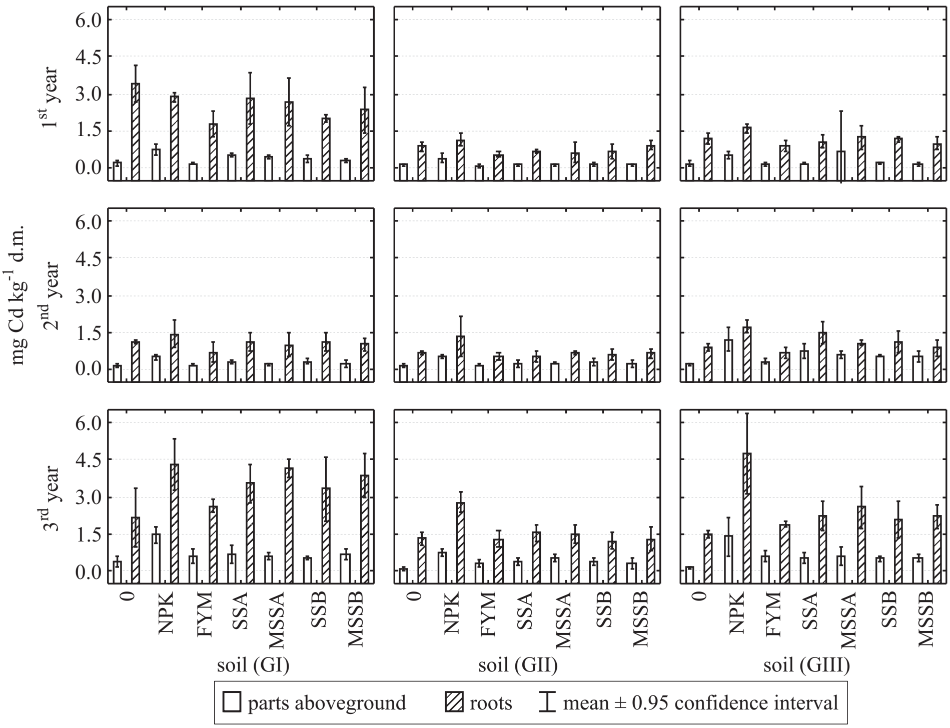

Fig. 6. Content of cadmium in parts aboveground and roots of maize from three years of the experiment on three soils

cadmium forms in soil in relation to fertilization with mixtures of sewage sludge and peat. Plant response expressed by the quantity of yield from mineral salt (NPK) treatments deserves attention. Greater yields from this treatment were registered in the first year of the investigations. In the subsequent years yield response to fertilization with organic materials was positive despite blurring differences on lighter soils. It resulted from so called consequent effect of organic fertilizers which additionally reinforced by supplementary doses of mineral fertilizers positively affected maize yield.

Conclusion

1. In comparison with organic materials supplied to the soil, fertilization with mineral salts significantly increased cadmium concentrations in maize biomass.

2. Soil pH affected cadmium mobility more than fertilization with sewage sludge and its mixtures with peat.

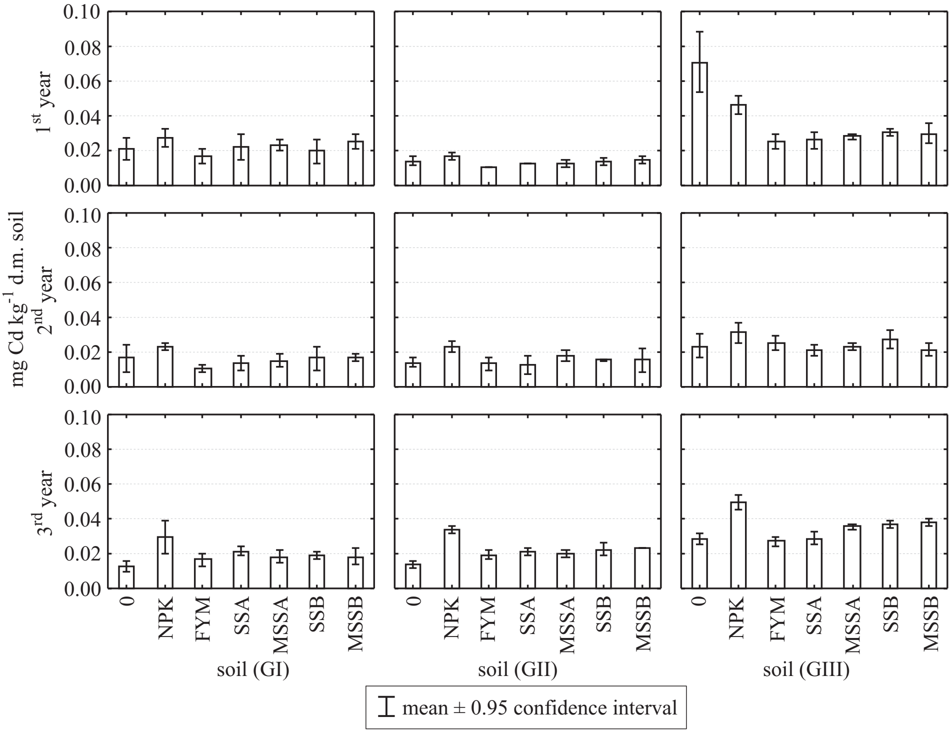

Fig. 7. Content of mobile forms of cadmium in soils from three years of experiment on three soils

3. Mixtures of sludge and peat (in comparison with sewage sludge applied separately) slightly more positively affected maize biomass yield and comparably cadmium content in the plant biomass.

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