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Research Article

YIELDING AND CONTENT OF SELECTED MICROELEMENTS IN MAIZE FERTILIZED WITH VARIOUS ORGANIC MATERIALS

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ABSTRACT
The paper aimed at comparing the yield and concentrations of zinc, copper and nickel in maize cultivated in soil fertilized with two different sewage sludge with yielding of maize fertilized with manure and solely with mineral fertilizers. The experiment was conducted in plastic pots, of which each contained 8.5 kg of air-dried soil with granulometric composition of light sandy loam and neutral pH. Sewage sludge used for the experiment originated from two municipal sewage sludge treatment plants in Krzeszowice (sludge I) and Niepołomice (sludge II), while manure from a private farm in Czernichów district. The test plant was maize (*Zea mays*) cultivated for 74 days and then harvested for green forage. On the basis of conducted research it was found that various fertilizer combinations applied in the experiment had a significant influence on the test plant yielding. All compared fertilizer variants allowed maize to produce statistically significantly higher yield in comparison with the yield harvested from the unfertilized soils. Fertilization with sewage sludge I supplemented with mineral treatment and application of solely mineral salts proved the most beneficial for the maize yield. Applied fertilizer combinations affected the content of microelements. The highest concentrations of nickel in maize green mass were assessed in plant samples from the unfertilized object, whereas zinc and copper from mineral fertilization variant. Except of zinc, introducing additional metal doses did not influence their increased content in plant organs. Soil enrichment with zinc contained in sewage sludge I and II (respectively 77.4 mg and 49.9 mg · pot^{-1}) contributed to its elevated concentration in maize roots but at the same time this metal content statistically significantly decreased in maize shoots in comparison with the amounts determined in plants fertilized with mineral materials.

Keywords: yield, maize, microelements, sewage sludge

INTRODUCTION

Constantly increasing volume of municipal sewage sludge has been observed for many decades in Poland. The amount of their yearly production has doubled during the last decade reaching 540.3 thousand Mg d.m. in 2013 [Ochrona środowiska 2014]. According to the forecasts published in "National Waste Management Plan" [Krajowy plan 2010] there will be about 726 thousand Mg d.m. of municipal sewage sludge produced in 2018 and 746 thousand Mg d.m. in 2022. According to this plan in 2018 about 40% of the total mass of produced sewage sludge will find environmental applications (composting, land reclamation, etc), of which ¼ will be used in agriculture, which gives over 70,000 Mg d.m. per year. This mass in comparison with the amount of manure produced in Poland is small, since it constitutes about 0.5% of its annual production [Ochrona środowiska 2014]. However, locally, particularly at a deficiency of natural fertilizers, municipal sewage sludge may provide some alternative.

Despite the fact that sewage sludge belong to wastes [Ustawa 2001], they may be used, among others as fertilizers, if the appropriate guidelines are observed [Ustawa 2001, Rozporządzenie 2015]. These materials generally reveal a high content of organic substance, nitrogen, phosphorus, calcium or magnesium, but also contain trace elements, *i.e.* zinc, copper and nickel, crucial for proper functioning of plants [Wieczorek and Frączek 2013, Gambuś and Wieczorek 2012]. However, because of possible accumulation of toxic heavy metals (Cd, Cr, Hg and Pb), organic pollutants (pesticides, PAHs, PCBs, dioxins, furans) or pathogenic microorganisms, their application to the soil involves some risk connected with the pollutant supply to the environment [Stevens et al. 2003, Shomar et al. 2004, Eljarrath et al. 2008, Smith 2009, Tabak 2015, Meng 2016, Antonkiewicz et al. 2017].

The paper aimed at comparing the yield and concentrations of zinc, copper and nickel in maize cultivated in soil fertilized with two different sewage sludge with yielding of maize fertilized with manure and solely with mineral fertilizers.

MATERIALS AND METHODS

The experiment was conducted in plastic pots, of which each contained 8.5 kg of air-dried soil with granulometric composition of light sandy loam and neutral pH. The soil was characterized by a low content of available phosphorus, very high contents of potassium and high magnesium. Sewage sludge used for the experiment originated from two municipal sewage sludge treatment plants in Krzeszowice (sludge I) and Niepołomice (sludge II), while manure from a private farm in Czernichów district. The sewage sludge met all requirements stated by the Decree of the Minister of the Natural Environment [Rozporządzenie 2015] for sludge destination for agricultural use. Five different fertilizer variants were applied: 1. without fertilization – control, 2. only mineral fertilization, 3. manure fertilization (FYM), 4. treatment with sludge I and 5. treatment with sludge II. The dose of organic materials was established on the basis of their nitrogen concentrations, 1.5 g N per pot and 1 g N per pot on treatment 2 receiving mineral fertilization. The differences in the amount of macroelements (K, P, Ca and Mg) supplied with various organic materials were corrected by supplementary fertilization with mineral salts to the quantity in the organic fertilizer most abundant in a given component. N:P:K ratios on the mineral treatment (2) and organic materials treatments (3–5) were different, respectively: 1:0.9:0.83 and 1:0.67:0.65. The experiment was conducted in four replications.

The test plant was maize (*Zea mays* L.) cultivated for 74 days and then harvested for green forage. During harvest, the aboveground shoots and roots for analyses were gathered separately. After drying the dry mass yield was determined. Samples of fertilizer materials were incinerated at 450ºC for 12 hours and then dissolved in a mixture of nitric and perchloric acids (3:2, v/v). Gathered plant parts were "dry" mineralized by dissolving the acid in HCl (1:1, v/v) and HNO_3 (1:2, v/v) acids. In filtrates prepared in this way mineral components were assessed by means of ICP-OES method. The content of zinc, copper and nickel were determined in plant part samples. Analysis of nitrogen in sewage sludge and manure was conducted using Kjeldahl's method.

Statistical computations and the layout were prepared using Statistica w. 12 PL and Microsoft Office Excel 2003 calculation sheet. The significance of differences between means was conducted on the basis of one-way ANOVA and Fishers' test setting homogenous groups.

RESULTS AND DISCUSSION

Organic fertilizer materials used in the experiment differed considerably by their chemical composition (Table 1). Municipal sewage sludge I (from Krzeszowice) was characterized by the lowest organic matter content. The content of macro- and microelements was greatly diversified between individual organic materials. Sewage sludge II proved the most abundant in nitrogen and calcium, but it contained the least of phosphorus, potassium and calcium among the three fertilizers. The highest concentrations of phosphorus and magnesium were determined in sewage sludge II and potassium in manure. The microelement content in municipal sewage sludge clearly exceeded the quantities assessed in the manure. The content of zinc in sewage sludge was on average 4 times, nickel 3.5 times and copper 2.5 times higher than the contents in the manure. Depending on the applied organic fertilization total amount of these macroelements supplied to the soil on individual treatments was

Table 1. Chemical composition of farmyard manure and sewage sludge used in experiment

Parameter	Unit	Farmyard manure	Sewage sludge I (Krzeszowice)	Sewage sludge II (Niepołomice)
Dry matter	g · kg^{-1}	206	170	232
Organic matter	g · kg^{-1}d.m.	799	525	671
N		26.0	36.0	47.3
P		17.4	19.9	11.8
K		16.5	1.9	1.0
Ca		9.1	30.3	40.2
Mg		4.4	5.8	3.6
Cd	mg · kg^{-1}d.m.	0.84	6.32	2.98
Cr		2.82	42.4	39.6
Cu		59.5	154	178
Ni		6.72	24.6	22.5
Pb		1.91	105	41.8
Zn		444	1867	1571

different. The soil fertilized with manure received in each pot: 25.6 mg Zn, 0.39 mg Ni and 3.43 mg Cu, whereas a single dose of sewage sludge I supplied: 77.4 mg Zn, 1.02 mg Ni and 6.39 mg Cu, a dose of sewage sludge II brought in: 49.9 mg Zn, 0.72 mg Ni and 5.66 mg Cu.

On the basis of conducted research it was found that various fertilizer combinations applied in the experiment had a significant influence on the test plant yielding (Fig. 1).

All compared fertilizer variants allowed maize to produce statistically significantly higher yield in comparison with the yield harvested from the unfertilized soils (treatment 1). Fertilization with sewage sludge I supplemented with mineral treatment (treatment 4) and application of solely mineral salts (treatment 2) proved the most beneficial for the maize yield. Statistically significantly lower yields were obtained on the soil from variants 5 and 3, treated with respectively sewage sludge II and manure, however they were higher by respectively 89 and 72% in comparison with maize yielding in the unfertilized soil. The obtained results were partially corroborated by works of other authors. While comparing yield forming activity of among others, sewage sludge, manure and mineral fertilization, Hryńczuk and Weber [2003] observed than in the first two years since their supply to the soil, the greatest yields of maize and winter wheat grain were harvested from the sludge treatment, then from manure fertilized object and the lowest were produced on the variant with mineral fertilization. In the third year of the research, manure proved the fertilizer with the best consequent effect on rapeseed grain. On the other hand, Gondek and Filipek-Mazur [2006] observed the same effect of municipal sewage sludge and manure on total yield of maize and mustard. Yields of plants fertilized with organic materials were statistically significantly

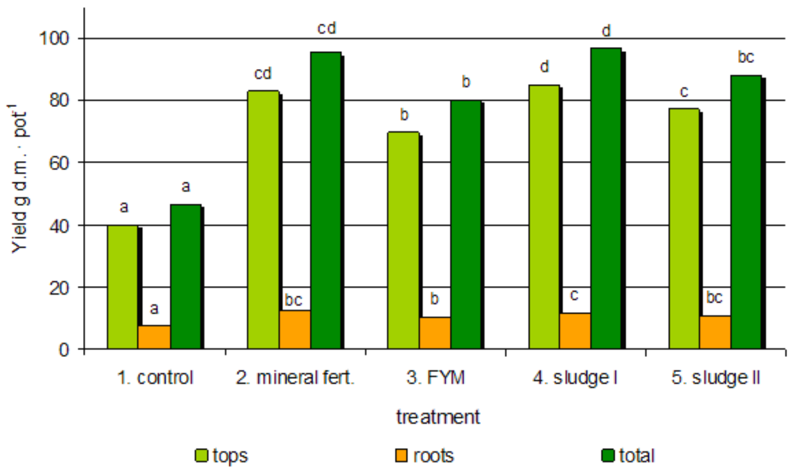

Fig. 1. Yield of tops and roots of maize dry matter; means marked by the same letters did not differ significantly at $\alpha < 0.05$ according to the Fisher test

higher than the yield obtained on the object fertilized solely with mineral salts.

Both the contents and uptake of zinc, nickel and copper by plants depend on these elements concentrations in soil, the soil properties and plant species [Gambuś 1997]. Maize belong to plants with high tolerance to elevated metal concentrations in soil, it blocks absorbed elements in roots and does not allow considerable increase in their content in the aboveground shoots [Gambuś 1997, Głowacka 2012]. Author's own research confirms this observation. Irrespective of the applied fertilization variant, microelement content assessed in maize shoots was definitely lower than their concentrations in roots. On average, there was thrice less of zinc, 10 times less of copper and even 40 times less of nickel (Table 2).

Zinc content in shoots ranging from 15–30 mg · kg^{-1} d.m. and copper over 2 mg · kg^{-1} d.m., [Kabata-Pendias and Pendias 2001] cover physiological requirements of majority of plants, whereas nickel as a microelement is necessary for plants only in trace amounts [Tabak and Gorczyca 2015]. An excess of microelements in crops is undesired because it may limit heir use. Their content in plant parts intended for forage use should not exceed 100 mg Zn, 50 mg Ni and 25 mg Cu in dry matter [Kabata-Pendias et al. 1993]. Metal concentrations assessed in the samples of analyzed plants were on the level regarded as physiologically natural. Applied fertilizer combinations affected the content and amount of absorbed microelements (Tables 2 and 3). The highest concentrations of nickel in maize green mass were assessed in plant samples from the unfertilized object, whereas zinc and copper from mineral fertilization variant. Except of zinc, introducing additional metal doses did not influence their increased content in plant organs. Soil enrichment with zinc contained in sewage sludge I and II (respectively 77.4 mg and 49.9 mg · pot^{-1}) contributed to its elevated concentration in maize roots but at the same time this metal content statistically significantly decreased in maize shoots in comparison with the amounts determined in plants fertilized with mineral materials.

It seems that the cause of this phenomenon lies in supplying additional amounts of organic matter and calcium with organic materials (Table 1), which efficiently limited zinc and other metals availability to plants. Total uptake of zinc, nickel and copper by plants was higher on the soil fertilized with mineral salts. The lowest amount of absorbed microelements characterized yield of maize cultivated in unfertilized soil. Analyzing the obtained results it may be stated that under

Table 2. Zinc, nickel and copper content in tops and roots of maize

Treatment	Tops			Roots		
	Zn	Ni	Cu	Zn	Ni	Cu
1. Control	31.2 b*	0.78 b	2.31 b	91.1 a	20.8 ab	31.2 b
2. Mineral fertilizers	37.0 c	0.53 a	3.37 c	87.7 a	23.3 ab	30.6 b
3. Farmyard manure	24.6 a	0.52 a	2.02 a	90.4 a	25.9 b	31.7 b
4. Sewage sludge I	29.5 b	0.49 a	2.53 b	109.1 b	17.8 a	31.3 b
5. Sewage sludge II	24.6 a	0.50 a	1.90 a	115.0 b	15.5 a	23.8 a

* Means in columns marked by the same letters did not differ significantly at $\alpha < 0.05$ according to the Fisher test

Table 3. Uptake of zinc, nickel and copper by maize [mg · pot^{-1}]

Element	Organ	Treatment				
		1	2	3	4	5
Zn	Tops	1.248	3.069	1.718	2.511	1.897
	Roots	0.227	0.458	0.251	0.343	0.268
	Total	1.475 a	3.526 d	1.969 b	2.854 c	2.166 b
Ni	Tops	0.031	0.044	0.036	0.042	0.039
	Roots	0.006	0.007	0.005	0.006	0.005
	Total	0.037 a	0.051 b	0.042 ab	0.047ab	0.044 ab
Cu	Tops	0.092	0.280	0.141	0.215	0.147
	Roots	0.017	0.042	0.021	0.029	0.021
	Total	0.109 a	0.321 d	0.162 b	0.245 c	0.167 b

* Means in line marked by the same letters did not differ significantly at $\alpha < 0.05$ according to the Fisher test

conditions of the experiment, the content of microelements and their uptake depended to a greater extend on physico-chemical properties of soil than on total metal concentrations in soil.

CONCLUSIONS

1. Soil fertilization with municipal sewage sludge combined with supplementary mineral fertilization and treatment with solely mineral fertilizers most beneficently affected maize crop yield.
2. Great amount of organic substance in the form of municipal sewage sludge or manure supplied to the soil decreases the content in the aboveground parts and the amount of zinc and copper absorbed by maize in comparison with mineral fertilization.
3. Maize is plant which possesses a strong barrier on the way of zinc, copper and nickel transport from roots to shoots.

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