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THE EFFECT OF FERTILIZATION ON YIELDING AND HEAVY METALS UPTAKE BY MAIZE AND VIRGINIA FANPETALS (*SIDA HERMAPHRODITA*)

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Abstract: The purpose of the investigation was to assess the suitability of sewage sludge, brown coal and a mix of sewage sludge and brown coal to be used for fertilizing a light soil with an increased content of lead (I^0) and slightly contaminated with cadmium (II^0). The subject of tests were soil and plant samples taken from a pot experiment conducted during the years 2007–2009. The tests determined the effect of the type of fertilization on the pH and sorption properties of the soil, the contents of heavy metals in the soil and in the plants, and the volume of crops. The fertilization types applied had an effect of slightly increasing the soil pH. The application of sewage sludge, brown coal and the mix of sewage sludge with brown coal to the soil resulted in an improvement of the sorption properties of the soil. In the soil treated with sewage sludge and the mix of sewage sludge with brown coal, an increase in the contents of Cd, Zn and Pb was found. This increase was, however, small and did not change the degree of soil contamination with heavy metals. In the above-ground parts of plants fertilized with brown coal the concentration of heavy metals was lower than in biomass from plants cultivated on the control combination. The application of sewage sludge and the mix of sewage sludge with brown coal generally resulted also in a reduction of metal contents in the above-ground parts of the plants. This was the effect of enriching the soil with an organic substance that improves the sorption properties. From among the fertilization combinations tested, the application of either sewage sludge or the mix of sewage sludge with brown coal had the most favourable effect on the crop volume. It resulted in a twofold increase in the yield compared to the control combination.

INTRODUCTION

The results of numerous studies indicate that the assimilation of heavy metals by plants is determined by many factors, including: pH, organic matter content, the concentration of metals, the plant species, etc. [6, 10, 11].

The effective method for limiting the phytoassimilation of metals is by improving the sorption conditions through increasing the organic matter content of soil, while assuring the proper pH of the soil. A potential source of organic matter in soils could be unconventional fertilizing materials, such as composts, sewage sludge, brown coal, and others [2, 4, 7].

Numerous studies have been conducted recently on the utilization of sewage sludge and brown coal for soil reclamation [8, 14, 16]. These are substances that enhance the fertility and properties of poor and degraded soils.

The purpose of the investigation was to determine the usefulness of brown coal and sewage sludge, as well as their mixture, to be used with the aim of limiting the uptake of cadmium and lead by maize and Virginia fanpetals (*Sida hermaphrodita*).

MATERIALS AND METHODS

Tests were conducted under pot experiment conditions during the years 2007–2009. About 300 kg of soil were taken from a field located approx. 2 km north of the Czestochowa Steel Mill (Huta Częstochowa). The soil material was sampled according to the BN-78/9180-02 standard. The grain size analysis showed that, due to its contents of leachable matter (< 10%) according to the criteria developed by the Institute of Cultivation, Fertilization and Soil Science of Pulawy (Instytut Uprawy, Nawożenia i Gleboznawstwa Puławy), the soil can be ranked among soils of slightly acid reaction. The soil was characterized by slight contamination with cadmium (II^{o}), and an enhanced content of lead (I^{o}) [3]. The contents of nickel, copper and manganese were at the level of contents natural for very light soils.

Pots used in the experiment had a capacity of 14 dm^3, each. Maize and Virginia fanpetals (*Sida hermaphrodita*) were cultivated. For each of the plants, 5 fertilization combinations were applied, with each of the combinations was repeated in three pots. A detailed schematic of the experiment is shown in Table 1.

Table 1. The scheme of experiment

Fertilization combination	Mix content
0	control – 11kg soil
W	11 kg soil + 114 g brown coal (ok. 25t/ha)
Oś	11 kg soil + 300 g sewage sludge (ok. 25t/ha)
Oś + W	11 kg soil + 150 g sewage sludge + 57 g brown coal (ok. 25 t/ha)
NPK	11 kg soil + fertilize NPK, urea 1.2 g potassium of salt 1.2 g superfosfat 2.5 g dolomite 10 g (ok. 5 t/ha)

The sewage sludge dose was determined while taking account of the applicable regulations [12], the nutrient capacity of the soil and the requirements of the plants to be cultivated. The sewage sludge derived from the Dźbów Sewage Treatment Plant. It was characterized by good fertilization properties owing to its nitrogen, phosphorus and potassium contents. This was stabilized, dewatered sludge of a moisture content of 77%, and pH in H_2O of 7.10. The total heavy metal contents in the sludge did not exceed the permissible metal contents according to the regulations in force [12]. The contents of the examined metals in the sewage sludge were: Cd, 2.50 mg/kg and Pb, 40.0 mg/kg. Brown coal came from KWB Bełchatów (Bełchatów Brown Coal Mine), and belonged to the category of so called earthy coals. The brown coal, as used in the experiment, contained 30% of water, had pH in H_2O of 5.85, and was used in a broken-up form of a particle size less than 2 mm. The coal was not contaminated with heavy metals. It was used in the identical dose as the sewage sludge in order to be able to compare the results.

Fertilization dose was applied once and was mixed with the whole soil mass. Soil samples for analysis were taken from 5 randomly chosen locations in the pot using a soil sampling rod. The soil samples were put through a 2 mm-mesh sieve. Analyzes of the soil samples were made after the geochemical equilibrium had been settled prior to planting the plants. The plants were harvested in the first and the second year after the vegetation period had ended in October. The plant material was dried and ground.

The following assays were made on the soil samples:

– pH in H_2O and 1M KCl – by the potentiometric method,
– the moisture content of samples by the loss on drying (LOD) method according to PN-IOS-11465:1999,
– hydrolytic acidity in a 1M $(CH_3COO)_2Ca$ solution – by Kappen's method,
– the sum of basic exchange cations in a 0.1n HCl solution – by Kappen's method.

The soil and the plants were analyzed for:

– heavy metal contents after mineralizing the soil and the plants in concentrated HNO_3 with a Uni Clever microwave mineralizer using an ICP plasma spectrophotometer according to PN-IOS-11047:2001.

RESULTS AND DISCUSSION

The soil used for the experiments has an acid reaction. After the application of sewage sludge, a mixture of sewage sludge with brown coal and mineral fertilization, the pH value increased by approx. 0.2 units (Tab. 2). The reaction and organic matter content of soil are the most important factors influencing the solubility and availability of heavy metals to plants [8, 17]. Changes in the reaction are counteracted by a well developed sorption complex. The test results indicate that all of the fertilization types applied have improved the sorption properties of the soils, however to a different extent. The application of sewage sludge and the mixture of sewage sludge with brown coal most effectively influenced the increase of the sum of basic exchange cations, caused a clear increase in sorption capacity and the degree of sorption complex saturation with bases (Tab. 2). The capacity value above 6.6 cmol(+)/kg of soil indicates a very good capability to store nutrients. Many authors emphasize the positive effect of sewage sludges and brown coals on improving the sorption properties of soil [4, 7, 9].

Table 2. The influence of fertilizations for pH and properties of soil sorption capacity

Fertilization combination	pH_{H2O}	pH_{1MKCl}	H_h - hydrolytic acidity	S – sum of basic exchange cations	T– sorption capacity	V – degree of sorption complex saturation with bases
			cmol(+)/kg soil			%
O	6.00	5.70	2.80	3.05	5.83	52.1
W	5.90	5.68	2.80	4.70	7.30	63.0
Oś	6.21	5.99	2.51	5.15	7.66	67.2
Oś + W	6.18	5.96	2.55	5.00	7.55	66.3
NPK	6.13	5.93	2.20	4.00	6.20	64.5

The cadmium content of the soil used for the experiment was 1.17 mg/kg, while the content of lead in the reference soil was 37.00 mg/kg. The fertilizers introduced to the soil, except for brown coal, all caused an increase of the contents of cadmium and lead in the soil, but this had no effect on changing the degree of soil contamination with these heavy metals (Tab. 3).

Table 3. The content of cadmium and lead in soil (mg/kg of d.m.)

Fertilization combination	Cadmium	Lead
O	1.17 ± 0.02	37.00 ± 0.03
W	1.16 ± 0.01	36.60 ± 0.15
Oś	1.20 ± 0.01	37.60 ± 0.18
Oś + W	1.19 ± 0.02	37.20 ± 0.16
NPK	1.18 ± 0.01	37.10 ± 0.08

± standard deviation

The basic purpose of the tests was to determine the effect of diversified fertilization on the contents of cadmium and lead in maize and in Virginia fanpetals. For both plants grown on the reference soil, and contents of Cd and Pb were the highest compared to the other fertilization combinations. This regularity occurred in the first and second years of conducting the experiment. The lowest metal contents in the above-ground parts of maize and Virginia fanpetals were found after the application of brown coal or the mix of brown coal with sewage sludge. In the above-mentioned fertilization combinations, the cadmium content in maize decreased by 15–25% and in Virginia fanpetals by 15–30% compared to the control. The lead content after the application of brown coal and the mix of brown coal with sewage sludge decreased by 20–30% in maize and by 15–18% in Virginia fanpetals as against the control (Tab. 4). The obtained results confirm the results

Table 4. The contents of heavy metals in the plants (mg/kg of d.m.)

Fertilization combination	Maize		Virginia fanpetals	
	I year	II year	I year	II year
	Cadium			
O	0.45 ± 0.04	0.56 ± 0.04	0.19 ± 0.02	1.28 ± 0.09
W	0.36 ± 0.03	0.45 ± 0.02	0.13 ± 0.01	1.10 ± 0.11
Oś	0.40 ± 0.02	0.51 ± 0.03	0.16 ± 0.02	1.20 ± 0.06
Oś + W	0.38 ± 0.01	0.42 ± 0.04	0.13 ± 0.01	1.01 ± 0.05
NPK	0.40 ± 0.02	0.50 ± 0.02	0.13 ± 0.01	1.11 ± 0.09
Lead				
O	1.98 ± 0.09	2.05 ± 0.16	2.92 ± 0.11	4.90 ± 0.14
W	1.36 ± 0.10	1.63 ± 0.08	2.50 ± 0.09	4.10 ± 0.09
Oś	1.66 ± 0.16	1.72 ± 0.09	2.90 ± 0.12	4.66 ± 0.10
Oś + W	1.35 ± 0.09	1.63 ± 0.05	2.51 ± 0.10	4.02 ± 0.03
NPK	1.67 ± 0.08	1.78 ± 0.06	2.58 ± 0.09	4.26 ± 0.14

± standard deviation

of studies by other authors [5, 7], where the addition brown coal decreased the contents of heavy metals in plants. The limitation of the mobility of metals is associated with the large amount of organic matter introduced with fertilizers, which has the properties of complexing heavy metals. With an increased amount of humus compounds, less soluble chelate compounds form, and with increasing pH their stability increases [1].

From among the fertilization types examined, sewage sludge and the mix of sewage sludge with brown coal had the most favourable effect on increasing the crop of the both plants. With these fertilization combinations, yields by 1.5 to 2.0 times greater than those from the control soil were obtained. The organic matter introduced with the fertilizers is a rich source of N, P, K, Mg and Ca, as well as microelements, for plants. Brown coal alone is less rich in nutrients than sewage sludge and its mixture with brown coal, so the volume of crops obtained from this fertilization type was smaller compared to the soil fertilized with sewage sludge and with the mix of sewage sludge with brown coal, however it was still greater by 20% compared to the control soil (Tab. 5). The favourable influence of organic matter on plant yielding is confirmed by numerous studies by other authors [1, 5]. It follows from numerous publications on the role of humus compounds in cell metabolism that, by entering the cytoplasm interior, the humus compounds enhance the efficiency of enzymes contained there, which in turn favourably influences the take-up of mineral components by the plants [13, 15].

Table 5. Crops of the maize and Virginia fanpetals (g /vase)

Fertilization combination	Maize		Virginia fanpetals	
	I year	II year	I year	II year
O	18.10 ± 1.30	20.00 ± 1.02	20.15 ± 1.14	24.50 ± 1.20
W	21.90 ± 1.15	23.85 ± 0.09	25.50 ± 1.08	30.25 ± 3.02
Oś	32.05 ± 2.20	42.20 ± 2.14	39.60 ± 2.05	48.20 ± 2.18
Oś + W	29.60 ± 2.12	39.60 ± 2.10	38.45 ± 1.19	46.15 ± 2.05
NPK	27.80 ± 0.92	35.15 ± 3.01	35.20 ± 2.16	42.00 ± 1.62

± standard deviation

CONCLUSIONS

1. Fertilization with sewage sludge and the mix of sewage sludge with brown coal increased the sorption capacity of soil and the contents of basic cations in the sorption complex most effectively of all fertilization combinations tested.
2. The amounts of metals taken up by the plants depended on the metal species, its soil concentration, the plant species, as well as on the fertilization type applied.
3. The application of brown coal and its mix with sewage sludge most effectively reduced the bioassimilability of lead and cadmium. Depending on the plant and metal species, the reduction of Pb and Cd concentrations in the biomass ranged from 15 to 30%.
4. In spite of causing the highest Cd and Pb concentrations in the soil, the application of sewage sludge did not result in the highest uptake of these elements by the plants. This was due to the effect of enriching the soil with humus and increasing the pH.

5. The application of sewage sludge and the mix of sewage sludge with brown coal, as expressed by the plant crop volume, was of the highest fertilizing value.

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WPŁYW NAWOŻENIA NA PLONOWANIE I POBIERANIE METALI CIĘŻKICH PRZEZ KUKURYDZĘ I ŚLAZOWIEC PENSYLWAŃSKI

Celem badań była ocena przydatności stosowania osadów ściekowych, węgla brunatnego i mieszaniny osadów ściekowych z węglem brunatnym do nawożenia gleby lekkiej o podwyższonej zawartości ołowiu (I^0) i słabo zanieczyszczonej kadmem (II^0). Przedmiotem badań były próbki glebowe i roślinne pobrane z doświadczenia wazonowego prowadzonego w latach 2007–2009. Określono wpływ nawożenia na pH gleby, właściwości sorpcyjne, zawartość metali ciężkich w glebie i roślinach, wysokość plonów. Zastosowane rodzaje nawożenia nieznacznie wpłynęły na zmianę pH gleby. Nawożenie gleby osadami ściekowymi, węglem brunatnym i mieszaniną osadów z węglem brunatnym spowodowało poprawę właściwości sorpcyjnych gleby. W glebie nawożonej osadami ściekowymi i mieszaniną osadów z węglem brunatnym stwierdzono wzrost stężenia Cd, Zn i Pb w glebie. Wzrost ten był niewielki i nie wpłynął na zmianę stopnia zanieczyszczenia gleby metalami ciężkimi. W częściach nadziemnych roślin nawożonych węglem brunatnym stężenie metali ciężkich było niższe niż w biomasie roślin uprawianych na kombinacji kontrolnej. Nawożenie osadami i mieszaniną osadów z węglem brunatnym też na ogół spowodowało obniżenie stężenia metali w częściach nadziemnych roślin. Było to efektem wzbogacenia gleby w substancję organiczną, poprawiającą właściwości sorpcyjne. Spośród badanych kombinacji nawożenia najkorzystniej na wysokość plonów wpłynęło nawożenie osadami ściekowymi i mieszaniną osadów z węglem brunatnym. Spowodowało ono ok. 2-krotny wzrost plonów w porównaniu z kombinacją kontrolną.