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PHYTOEXTRACTION OF ZINC, LEAD AND CADMIUM WITH *Silene vulgaris* MOENCH (GARCKE) IN THE POSTINDUSTRIAL AREA

FITOEKSTRAKCJA CYNKU, OŁOWIU I KADMU PRZEZ *Silene vulgaris* MOENCH (GARCKE) NA TERENACH POPRZEMYSŁOWYCH

Abstract: For the purpose of our study we have selected the perennial herb *Silene vulgaris* (*Caryophyllaceae*) which is characteristic for many metal-enriched soils in Europe to measure the *in situ* phytoextraction of zinc, lead and cadmium in the postindustrial area. *Silene vulgaris* belongs to the metalollophytes. The plant material and the soil samples (from upper layer) were collected from the vicinity of the non-ferrous metal smelter Szopienice at the distances of 50, 250, 450 m from zinc waste heap in Katowice and from the former calamine site in Dabrowa Gornicza in September 2003–2005. The soil located near the smelter Szopienice was the most polluted area and the site exhibited differences in the heavy metal concentration (metals extracted with 10 % HNO_3) in the upper layer (66640–6455 mg/kg Zn, 119–39 mg/kg Cd, 1280–1011 mg/kg Pb). The heavy metal bioavailability was low and connected with high pH values (6.7–7.8). Phytoextraction was calculated from the biomass and its concentration of metal. It was at a maximum at the distance of 450 m from the smelter (1119 g/ha Zn, 11 g/ha Pb and 6 g/ha Cd) for all the investigated metals. Only Zn amount accumulated in the aboveground plant parts seems to be promising for phytoextraction.

Keywords: heavy metals phytoextraction, *Silene vulgaris*, metallophytes

Phytoextraction is the use of plants to remove toxic elements from contaminated environments [1]. Some plant species were reported to accumulate metals from the soil in their aboveground biomass. The ideal plant to use in phytoextraction should have the ability to accumulate the metals intended to be extracted, preferably in aboveground parts, but above all it has to tolerate very high metal concentrations in soils [1–3]. The efficacy of phytoextraction is related to the ability of hyperaccumulating plants to grow and develop their root systems and to take up and accumulate the available metals in the upper parts. The aerial parts would be dried and burnt to ashes. Unfortunately very often the production of biomass by the hyperaccumulators is slow and the root systems, with the exception of *Silene vulgaris*, small [4]. *Silene vulgaris* Moench (Garcke) (*Caryophyllaceae*) is a perennial herb, which is common in many metal-enriched soils in Europe. It belongs to metallophytes, which are tolerant of high heavy metals concen-

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tration and have high heavy metal accumulation ability [4–9]. This plant is widespread in the Upper Silesian Industrial Region on the old calamine heaps, in the smelter surroundings or the metallurgical waste dumps [7–11]. Such sites are characterized by the continuous and natural phytoextraction of metals, except for the fact that plants are not harvested. The absence of agricultural management (eg fertilization) is characteristic of these sites [1]. The aim of this work was to determine the *in situ* phytoextraction of zinc, cadmium and lead with metallophyte – *Silene vulgaris* Moench (Garcke) growing in the postindustrial areas: in the nearest vicinity of non-ferrous plant, on the zinc smelter spoil heap in Katowice and in the former calamine site in Dabrowa Gornicza. These sites exhibited varied heavy metal contamination level.

Material and methods

The investigation was carried out in September in 2003–2005. The plants of *Silene vulgaris*, Moench (Garcke) were collected in the nearest vicinity of nonferrous plant Szopienice at the distances of 50, 250, 450 m, on the zinc smelter spoil heap in Katowice-Welnowiec and from the former calamine site in Dabrowa Gornicza. In each place the aerial plant parts from 20 individuals from an area of 40 m^2 of 2 m in dia-meter were collected. In order to determine the heavy metal concentration, the plant material (aerial parts) was washed in tap and in distilled water, dried at 105 °C to a constant weight and ground to fine powder, then mineralized and dissolved in 10 % HNO_3. After filtration Zn, Pb and Cd contents were determined using flame Atomic Absorption Spectrometry (AAS) [12]. The quality of the analytical procedure was controlled by using the samples of the reference material in each series of analysis. (Certified Reference material CTA-OTL-1 Oriental Tobacco Leaves). The phytoextraction was calculated from the biomass and its concentration of metal. The soil samples from the 0–10 cm layer were collected in the same investigated places. Heavy metal contents were estimated according to the method of Bowman et al [13] and Ostrowska et al [11], in the air dried soil samples, which were sieved. Heavy metals were extracted using 0.01 M $CaCl_2$ (bioavailable fraction) and 10 % HNO_3. The analysis was conducted using the atomic absorption spectrometry. Soil pH was measured in water (1:2.5 soil:water ratio) using a pH meter, and organic matter content [%] was estimated by the Ostrowska's methods [12]. All plants and soil samples were determined in six replications. The data was processed using the software Statistica to compute significant statistical differences between samples ($p < 0.05$) according to Tukey's multiple range test.

Results and discussion

The previous researches showed a high decrease in the soil enzymes activity at the distance of 250 m from the smelter, where the highest heavy metals bioavailability was found. The reduction of enzymatic soil microorganism activity can cause inhibition of organic matter decomposition and the reduction of most biochemical processes in the soil. This effect leads to soil degradation [14]. Tables 1 and 2 present heavy metals content in the soil upper layer in the investigated area. The highest heavy metals bioavailability was noted in the soil collected in the distance of 250 m from the smelter. The chemical properties of the soils in the investigated areas are shown in Table 3. The low heavy metals bioavailability can be connected with relatively high pH values, which were within the range 6.7–7.8. The highest Cd (79 mg/kg dm) and Pb (109.7 mg/kg dm) Zn (8316 mg/kg dm) accumulation was noted in aerial plant parts collected at the distance of 250 m. The amount of Zn was almost 4.5 times higher than the content of this metal in the plants in the other areas (Tab. 4). All of the investigated metals were above or within the range (Cd) of toxic level similarly to previous study [7, 15, 16]. In pot experiment in EDTA presence in acid soil Zn, Cd and Pb (in Szopienice plant) were accumulated in higher amounts in the shoots. The higher translocation of Zn and Cd to shoots of *Silene vulgaris* was observed [16]

Table 1

Mean heavy metal contents in soil (HNO_3 extracted) in the investigated areas
Values with the same letter are statistically the same for $p < 0.05$.

Investigated area	Mean heavy metal contents in the soil (HNO_3 extracted) [14]					
	Cd	SD	Pb	SD	Zn	SD
50 m	119.3a	55.1	1280.3a	558.6	66638.4a	19184.8
250 m	40.5b	9.8	1011.1a	245.1	8513.7b	625.8
450 m	38.9c	11.8	1157.2a	115.9	6454.6b	1554.1
Heap	101.9ab	56.7	1404.2b	388.8	45732.2c	3377.1
C	54.7c	4.3	1139.03a	135.1	24578.9d	1965.6

Table 2

Mean heavy metal contents in soil ($CaCl_2$ extracted) in the investigated areas
Values with the same letter are statistically the same for $p < 0.05$.

Investigated area	Mean heavy metal contents in soil ($CaCl_2$ extracted)					
	Cd	SD	Pb	SD	Zn	SD
50 m	12.2a	1.9	43.8a	20.9	296.1a	22
250 m	13.2a	1.1	92.3a	37.8	431.9b	43.8
450 m	9.6b	0.6	41.3a	18.6	321.9a	84.6
Heap	6.3c	1.9	35.8a	17.9	211a	44.6
C	2.3d	0.8	53a	10.6	35.5c	20.1

Table 3

Soil properties (organic matter contents [%] and pH values); average ± SD
Values with the same letter are statistically the same for $p < 0.05$.

Mean organic mater contents [%] and pH values in soil				
Investigated area	Mean organic matter content	SD	Mean pH value	SD
50 m	4.4a	0.8	6.91a	0.02
250 m	2.7b	0.9	6.89a	0.14
450 m	4.6a	1.03	6.65a	0.11
Heap	8.1c	0.5	6.71a	0.19
C	9.7b	0.7	7.77b	0.11

Table 4

Heavy metal bioaccumulation in *Silene vulgaris* aerial parts in the investigated area
Values with the same letter are statistically the same for $p < 0.05$.

Investigated area	Mean heavy metal content in aerial plant parts [mg/kg d.m.]					
	Cd	SD	Pb	SD	Zn	SD
50 m	87	3.8	261.7	3.9	7019	90.8
250 m	78.8	1.2	109.7	4.7	8316	111.3
450 m	30.6	1.9	59	8.5	5843	375
Heap	6.7	0.5	69.8	5.2	6733.6	118
C	13.4	0.5	34.6	1.9	1875.8	204.6

The plant populations differed at various distances from the emitor. The highest biomass of *Silene vulgaris* aboveground parts was noted for the plants collected at the distance of 450 m from the smelter (194 kg d.m./ha Fig. 1). Lower biomass of the investigated plants in the calamine site was caused most likely by the competition between other plant species. Phytoextraction demands a reasonable aboveground, thus harvestable biomass. Most metal-hyperaccumulators have a low biomass production of less than 4 Mg per ha and per year [3]. Ernst pointed out [4] that only a few plant species have evolved metal specific ecotypes at different metal enriched soils and among these plants is *Silene vulgaris*. Various metals in polymetalic soils strongly affect the productivity of even the metal resistant plants. Metallophyte – *Silene vulgaris* biomass is also too low (Fig. 1). The obtained biomass results were lower than the biomass estimated for *Thlaspi caerulescens*

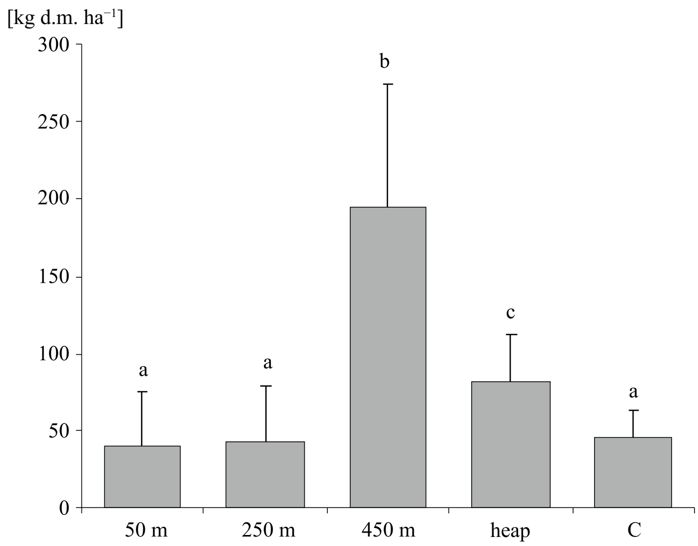

Fig. 1. *Silene vulgaris* biomass on the investigated stands

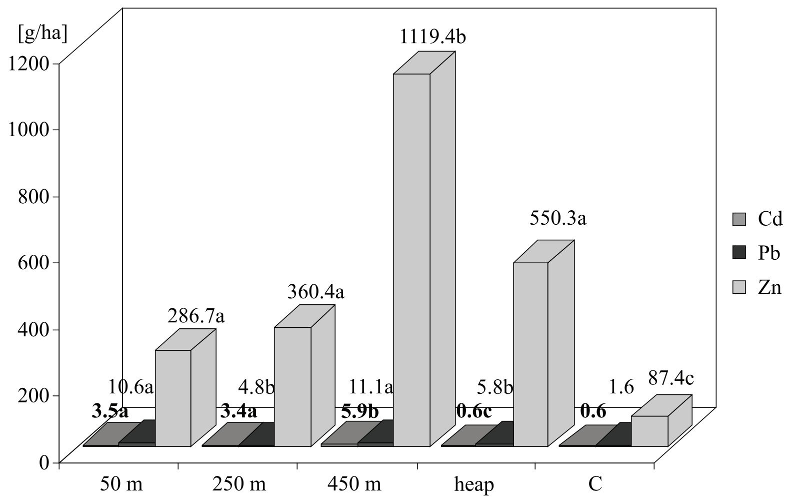

Fig. 2. Phytoextraction of Zn, Pb, Cd with *Silene vulgaris*

0.6–0.9 Mg/ha by Keller [18]. The plants collected at the distance of 450 m from the emitor exhibited the highest Zn, Cd and Pb *in situ* phytoextraction (1119 g/ha Zn, 11 g/ha Pb and 6 g/ha Cd, Fig. 2). Van Nevel pointed out that phytoextraction efficiency will decline under the increasing soil metal concentrations [19]. The quantity of Zn extracted by plants was 3 times higher than in the plants collected at the distance 250 m, where the highest heavy metals bioavailability and highest Zn accumulation in the plant aboveground parts were found and almost 13 times higher than the Zn extracted by *Silene vulgaris* on the calamine site. In Schwartz et al investigations [1] phytoextraction values ranging from 1.5 to 10 kg Zn ha^{-1} were recorded, involving the hyperaccumulator *A. halleri*. The examined *Silene vulgaris* does not have the ability to phytoextract Cd and Pb with high efficiency. Compared to *Rumex crispus* (high biomass plant) extracted 0.16 Cd kg ha^{-1} and below 1.6 Pb kg ha^{-1} and investigators pointed out that the plant used for the field experiment did not prove to have ability to phytoextract Pb with high efficiency [20]. Comparable amount of Zn extracted by *Silene vulgaris* indicated that it could participate only in this metal phytoextraction. On the other hand especially in extremely polluted sites the use of local vegetation may give an opportunity to create a soil cover. Polluted site related species have already proven its ability to survive under pollution stress. It is also recommended to use indigenous species for phytoextraction, as they are considerably cheaper than exotic species and do not create adaptation problems [21–22].

Conclusions

The heavy metals phytoextraction with *Silene vulgaris* was at a maximum at the distance of 450 m from the smelter (1119 g/ha Zn, 11 g/ha Pb and 6 g/ha Cd) for all investigated metals. Only Zn amount accumulated in the aboveground plant parts seems to be promising for phytoextraction. *Silene vulgaris* vegetation may give an opportunity to create a soil cover of the polluted site.

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FITOEKSTRAKCJA CYNKU, OŁOWIU I KADMU PRZEZ *Silene vulgaris* MOENCH (GARCKE) NA TERENACH POPRZEMYSŁOWYCH

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Abstrakt: Do badań wybrano rośliny zielne *Silene vulgaris*, które są charakterystyczne dla gleb o zwiększonym stężeniu metali ciężkich w Europie. Mierzono fitoekstrakcję cynku, ołowiu i kadmu na terenach poprzemysłowych. Roślina należy także do metalofitów. Materiał roślinny i próbki gleby pobierano we wrześniu 2002–2005 w najbliższych sąsiedztwie Huty Metali Nieżelaznych „Szopienice", na hałdzie pocynkowej w Katowicach i terenu po eksploatacji galmanu w Dąbrowie Górniczej. Zanotowano największe zanieczyszczenie gleby (metale ekstrahowano 2M HNO_3) z najbliższego sąsiedztwa HMN „Szopienice", gdzie wykazano również różnice w zawartości metali ciężkich w górnym poziomie gleby (66640–14000 mg/kg Zn, 119–39 mg/kg Cd, 1280–1100 mg/kg Pb). Biodostępność metali ciężkich była mała i związana z dość dużymi wartościami pH gleby (6,8–7,8). Fitoekstrakcję oznaczono na podstawie biomasy i koncentracji w niej metali ciężkich. Największą fitoekstrakcje zanotowano dla roślin w odległości 450 m od emitora (1119 g/ha Zn, 10 g/ha Pb i 6 g/ha Cd) dla wszystkich badanych metali. Tylko ilość Zn akumulowana w nadziemnych częściach roślin wydaje się być obiecująca dla procesu fitoekstrakcji.

Słowa kluczowe: metale ciężkie, fitoekstrakcja, *Silene vulgaris*, metalofity