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# EFFECT OF BOTTOM SEDIMENT ON CONTENT, BIOACCUMULATION AND TRANSLOCATION OF HEAVY METALS IN MAIZE BIOMASS

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Abstract

The research aimed to assess the effect of bottom sediment on the content, bioaccumulation and translocation of heavy metals in maize biomass. The investigations were conducted in 2006-2007 as a pot experiment on light soil of the granulometric composition of weakly-loamy sand. The experimental design comprised 3 treatments: without sediment (I), a 5% sediment admixture (II) and a 10% sediment admixture to the soil (III). Bottom sediment was added to the soil in the first year of the investigations. The content of Zn, Cu, Ni. Pb, Cd and Cr was determined using the ICP-EAS method in the plant material after its dry mineralization and ash solution in $HNO_3$. The uptake of the above-mentioned metals by maize was computed alongside their bioaccumulation and translocation coefficients. The effect of bottom sediment admixture on heavy metal concentrations in maize was determined to be varied, e.g. a 5% dose of sediment added to soil decreased the content of all the analyzed heavy metals in the biomass of maize aerial parts, whereas a 10% admixture increased the content of Cu, Ni, Pb and Cr. The values of bioaccumulation coefficients revealed that an admixture of both doses of bottom sediment led to a decreased accumulation of Zn, Cu, Cd, Cr and Ni (5% dose) in maize aerial biomass. Moreover, the plant more easily accumulated Zn, Cd and Cu than Cr, Ni or Pb. Permissible amounts of heavy metals in plants to be used as animal fodder were not exceeded in the maize biomass.

Key words: bottom sediment, heavy metals, maize.

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**WPŁYW OSADU DENNEGO NA ZAWARTOŚĆ, BIOAKUMULACJĘ I TRANSLOKACJĘ METALI CIĘŻKICH W BIOMASIE KUKURYDZY**

Abstrakt

Celem badań była ocena wpływu osadu dennego na zawartość, bioakumulację i translokację metali ciężkich w biomasie kukurydzy. Badania prowadzono w latach 2006-2007, w warunkach doświadczenia wazonowego, na glebie lekkiej o składzie granulometrycznym piasku słabogliniastego. Schemat doświadczenia obejmował 3 obiekty: bez osadu (I), z dodatkiem 5% osadu (II) i dodatkiem 10% osadu do gleby (III). Osad denny dodano do gleby w pierwszym roku badań. Zawartość Zn, Cu, Ni, Pb, Cd, Cr w materiale roślinnym oznaczono po suchej mineralizacji i roztworzeniu popiołu w $HNO_3$. Obliczono wynos ww. metali przez kukurydzę oraz ich współczynniki bioakumulacji i translokacji. Stwierdzono niejednoznaczny wpływ dodatku osadu dennego na zawartość metali ciężkich w kukurydzy. Osad dodany w ilości 5% do gleby wpłynął na zmniejszenie zawartości wszystkich analizowanych metali w nadziemnej biomasie kukurydzy, natomiast 10% dodatek osadu na zwiększenie ich zawartości (Cu, Ni, Pb, Cr). Wartości współczynników bioakumulacji świadczą, że dodatek osadu dennego w obu dawkach spowodował zmniejszenie akumulacji Zn, Cu, Cd, Cr oraz Ni (dawka 5%) w biomasie nadziemnej kukurydzy, ponadto rośliny łatwiej akumulowały Zn, Cd i Cu niż Cr, Ni i Pb. W biomasie kukurydzy nie stwierdzono przekroczenia dopuszczalnych zawartości metali ciężkich przyjętych do oceny roślin pod względem ich przydatności paszowej.

Słowa kluczowe: osad denny, metale ciężkie, kukurydza.

# INTRODUCTION

Most of the toxic substances, including heavy metals, which reach open waters as a result of human economic activities are trapped in bottom sediments. Bottom deposits which accumulate these substances are therefore an important source of information about the degree of anthropopressure on water environment (Bojakowska 2001). Another crucial aspect of the pollution of bottom sediments is how to handle or dispose of them after their extraction from the bottom of rivers, dam reservoirs, ports, channels or ponds (Fonseca et al. 1998, Madeyski 2003, Popenda et al. 2007). Many authors emphasize that utilization of bottom sediments free from chemical or biological pollution in agriculture may be of considerable environmental and ecological importance and may prove to be the most rational way of their management (Fonseca et al. 1998, 2003, Pleczar et al. 1998, Wiśniowska-Kielian, Niemiec 2007ab). The research aimed to assess the effect of bottom sediment on the content, bioaccumulation and translocation of heavy metals in maize biomass.

## MATERIAL AND METHODS

The investigations were conducted in 2006-2007 as a pot experiment. The experiment was conducted on light soil of the granulometric composition of weakly-loamy sand and $pH_{KCl}$ 6.21. With respect to the threshold levels of heavy metals in soil, the investigated soil had natural content of Cu, Pb, Ni, Cd and elevated content of Zn (KABATA-PENDIAS et al. 1995). Bottom sediments originated from a small retention reservoir localized in the village of Zesławice, 8.7 km of the Dłubnia River (Province of Małopolska, *województwo małopolskie*) (JASIEWICZ, BARAN 2006). The bottom sediment was classified as ordinary silt deposit of $pH_{KCl}$ 7.35. It had a low content of available phosphorus and potassium but a high content of magnesium (Table 1). The bottom sediment evaluation concerning heavy metal concentrations was conducted according to the *Ordinance of the Minister of the Natural Environment* on types and concentrations of substances which cause yield pollution (Dz.U. 2002 nr 55, poz. 498), whereas the way it was handled was determined with respect to the IUNG criteria (KABATA-PENDIAS et al. 1995) and the *Ordinance of the Minister of the National Environment* on soil quality standards and earth quality standards (Dz.U. 2002, nr 165, poz. 1359). According to the above regulations and the IUNG assessment, the levels of heavy metal in the analyzed sediment did not exceed the content admissible for yield or for the soil and land of group B, and was classified as natural (degree 0) – Table 1.

Air dry bottom sediment was added to the soil in the first year of the investigations. The experimental design comprised 3 treatments: without sediment (I), a 5% sediment admixture (II) and a 10% sediment admixture to the soil (III). The same NPK fertilization, i.e. 1.8 g N, 1.1. g P, and 2.2 g K per pot (8 kg soil d.m.), was applied to all the treatments. The mineral salts $NH_4NO_3$; $KH_2PO_4$ and KCl were added each time prior to the test plant sowing.

Table 1

Selected properties of bottom sediment

| Share of Ø (mm) fraction | | | Org. matter | Total N | $P_2O_5$ | $K_2O$ | Mg |
|---|---|---|---|---|---|---|---|
| 1-0.1 | 0.1-0.02 | <0.02 | (g $kg^{-1}$ d.m.) | | (mg $kg^{-1}$ d.m.) | | |
| 8% | 66% | 26% | 25.8 | 1.0 | 44.6 | 69.7 | 117.4 |
| Heavy metals (mg $kg^{-1}$ d.m.) | | Cr | Zn | Pb | Cu | Cd | Ni |
| | | 15.0 | 76.31 | 12.85 | 12.23 | 0.35 | 11.0 |
| Norm* | | <200 | <1000 | <200 | <150 | <7,5 | <75 |
| Norm (grounds B)** | | 150 | 300 | 100 | 150 | 4 | 1 |
| IUNG | | - | <100 | <70 | <40 | <1 | <50 |

*Journal of Laws of 2002, no. 55, item 498, **Journal of Laws of 2002, no. 165, Item 1359

After harvest, the plant material was dried in a dryer with forced air flow at 65°C, after which the plant material was comminuted in a laboratory mill and subjected to chemical analysis. The content of Zn, Cu, Ni, Pb, Cd and Cr in the plant material was determined using the ICP-EAS method after its dry mineralization and ash solution in $HNO_3$. The uptake of the above-mentioned metals by maize was computed, as well as their bioaccumulation and translocation coefficients. The results were verified statistically by means of one way ANOVA and Tukey test at significance level $\alpha$ =0.05, using Statistica 8.1. programme.

## RESULTS AND DISCUSSION

Our analysis of zinc distribution in the plant revealed that its roots contained on average 34% more of this metal than the aerial parts (Table 2). The highest Zn concentrations both in the aerial parts and roots found among the experimental treatments were in the control plants (Table 2). Significantly smallest quantities of zinc were assessed in the plants from treatments with a 5% supplement of the sediment to the soil. In these treatments, maize had 29% less of Zn (aerial parts) and 27% (roots) in comparison with the object without the sediment. The admixture of both bottom deposit doses to the soil significantly diminished Zn content in maize roots (Table 2). It might have been connected with the bottom sediment effect on the soil pH, where an increase in pH value decreases zinc bioavailability,

Table 2

Heavy metal content in maize

| Treatment | Shoots (mg kg$^{-1}$ d.m.) | | | | | |
|---|---|---|---|---|---|---|
| | Zn | Cu | Ni | Pb | Cd | Cr |
| Soil without sediment | 35.39$^{b}$ | 1.55$^{ab}$ | 0.30$^{ab}$ | 0.74 | 0.23$^{b}$ | 0.59 |
| Soil+ 5% sediment | 25.07$^{a}$ | 1.20$^{a}$ | 0.26$^{a}$ | 0.73 | 0.13$^{a}$ | 0.54 |
| Soil +10% sediment | 34.20$^{b}$ | 1.61$^{b}$ | 0.40$^{c}$ | 0.85 | 0.22$^{ab}$ | 0.61 |
| $LSD_{0.05}$ | 5.60 | 0.33 | 0.11 | s.n. | 0.09 | s.n. |
| Treatment | roots (mg kg$^{-1}$ d.m.) | | | | | |
| | Zn | Cu | Ni | Pb | Cd | Cr |
| Soil without sediment | 58.65$^{b}$ | 4.02$^{ab}$ | 2.07 | 4.09 | 1.93$^{b}$ | 2.00 |
| Soil+ 5% sediment | 42.56$^{a}$ | 4.77$^{b}$ | 2.35 | 3.59 | 1.49$^{a}$ | 1.92 |
| Soil +10% sediment | 43.02$^{a}$ | 2.90$^{a}$ | 2.28 | 3.84 | 1.74$^{ab}$ | 1.66 |
| $LSD_{0.05}$ | 7.15 | 1.41 | s.n. | s.n. | 0.25 | s.n. |

s.n. – statistically non-significant

whereas a decline in pH value favours zinc availability to plants. The bottom sediment had alkaline reaction ($pH_{KCl}$ 7.35) and therefore caused worse zinc solubility in soil.

The present investigations revealed that maize roots accumulated between 1.8- and 4-fold more copper than the aerial parts (Table 2). An admixture of bottom sediment to the soil did not produce an identical effect on the copper concentrations in maize biomass. Significantly the highest concentrations of this metal were found in maize aerial parts from the treatment with a 10% supplement of bottom deposit, and in roots from the treatment with a 5% share of bottom sediment in the soil. The lowest copper content in the aerial biomass was assessed in the treatment with a 5% share of the sediment and in roots in the treatment where a 10% admixture was used to light soil. In both cases, the relationships were statistically significant (Table 2).

In our experiment, maize roots had on average 86% more nickel than aerial parts. In the aerial biomass, the highest and statistically significant nickel concentrations were registered on the variant with a 10% admixture of bottom deposit to the soil whereas the lowest ones appeared in the variant with a 5% share (Table 2). The aerial parts from these treatments contained 25% more (10% of sediment) and 13% less Ni (5% of sediment) in comparison with the control. An admixture of bottom deposit to light soil increased nickel concentrations in roots, but the differences were statistically non-significant. WIŚNIOWSKA-KIELIAN and NIEMIEC (2007a) obtained slightly different results, i.e. between 1 and 4% admixture of bottom sediment led to increaed nickel accumulation in maize aerial biomass, whereas an over 6% sediment supplement diminished its content. These authors found the highest nickel concentrations in maize roots in treatment with a 10% admixture of bottom sediment.

Maize roots accumulated over 4.5- to 5-fold more lead than the aerial parts (Table 2). The results confirm the hypothesis that relatively big quantities of lead present on the root surface are a mechanism limiting this metal uptake from soil (BARANOWSKA-MOREK 2003). An admixture of bottom sediment to soil did not diversify statistically significantly the content of lead in the examined parts of maize. In the aerial parts, the highest Pb concentrations were determined in the treatment with a 10% bottom sediment admixture to the soil (Table 2). WIŚNIOWSKA-KIELIAN and NIEMIEC (2007a) reported different results, i.e. lower doses of bottom sediment, i.e. between 1 and 4% increased Pb content, whereas the doses higher than 6% led to a decrease in Pb concentrations in aerial biomass. In the present experiment, a bottom sediment admixture caused a decline in Pb root concentrations (Table 2). WIŚNIOWSKA-KIELIAN and NIEMIEC (2007a) also found that the lead content diminished in roots as a result of bottom deposit application but only at its highest, i.e. 16%, share. In another experiment, WIŚNIOWSKA-KIELIAN and NIEMIEC (2007b) demonstrated that lead accummulation in aerial parts and roots of oat and narrowleafed lupine became limited under the influence of as much as 10% bottom sediment admixture to the soil.

The maize roots contained 9% more cadmium than the aerial parts (Table 2). As for zinc, the applied bottom sediment caused a significant decrease in cadmium content in aerial parts and roots of maize in comparison with the treatment without the deposit. The lowest amounts of cadmium were found in the plants from the treatments with a 5% sediment supplement to the soil. A 5% sediment admixture lowered the cadmium level by 44% in maize aerial biomass and by 23% in roots in comparison with the object without the sediment (Table. 2). Similar relationships were reported from other studies, in which application of bottom sediment to soil led to a decline in the Cd content in maize, oat and narrowleafed lupine biomass (WIŚNIOWSKA-KIELIAN, NIEMIEC 2007ab).

The maize roots accumulated on average 69% more chromium in comparison with the aboveground biomass (Table 2). An admixture of bottom sediment to soil in 5 and 10% were not diversify statistically significantly the content of chromium in the aerial parts and roots of maize. The highest Cr concentrations in the aerial parts were found in the treatment with a 10% admixture of bottom sediment to the soil (Table 2). In the maize roots, a decrease in Cr content was noticed under the influence of both doses of bottom sediment added to the soil.

Considering the share of individual maize parts in the general element uptake, it was noticed that the highest amounts of elements were removed with the maize aerial biomass (Table 3), which absorbed 86% Zn, 77% Cu,

Table 3

Heavy metals uptake by maize

| Treatment | Shoots (mg kg$^{-1}$ d.m.) | | | | | |
|---|---|---|---|---|---|---|
| | Zn | Cu | Ni | Pb | Cd | Cr |
| Soil without sediment | 10.41$^{b}$ | 0.46 | 0.09 | 0.22b | 0.07 | 0.17 |
| Soil+ 5% sediment | 8.03$^{a}$ | 0.38 | 0.08 | 0.15a | 0.04 | 0.16 |
| Soil +10% sediment | 10.23$^{b}$ | 0.48 | 0.12 | 0.27c | 0.07 | 0.18 |
| $LSD_{0.05}$ | 1.86 | s.n. | s.n. | 0.04 | s.n | s.n. |
| Treatment | roots (mg kg$^{-1}$ d.m.) | | | | | |
| | Zn | Cu | Ni | Pb | Cd | Cr |
| Soil without sediment | 2.01$^{b}$ | 0.14$^{ab}$ | 0.07 | 0.14$^{b}$ | 0.07$^{b}$ | 0.07 |
| Soil+ 5% sediment | 1.42$^{a}$ | 0.16$^{b}$ | 0.09 | 0.07$^{a}$ | 0.05$^{a}$ | 0.06 |
| Soil +10% sediment | 1.31$^{a}$ | 0.09$^{a}$ | 0.07 | 0.13$^{ab}$ | 0.05$^{a}$ | 0.05 |
| $LSD_{0.05}$ | 0.34 | 0.05 | s.n. | 0.05 | 0.01 | s.n. |

s.n. – statistically non-significant

74% Cr, 66% Pb, 55% Ni and 51% Cd of the total heavy metal concentrations. On the other hand, the analysis of heavy metal uptake depending on the applied quantities of bottom sediment revealed a significantly lower uptake of Zn, Cd (roots), Cu (roots), and Pb (5% dose). Plants growing on soil with a 5% addition of bottom sediment were characterized by the lowest metal uptake, which resulted from the highest maize yields from this treatment. Additionally, the aerial biomass produced from this treatment revealed the lowest metal concentrations (Table 2). In this treatment, 39% Pb, 31%Cd, 24% Zn, 9% Cr and 8% Cu less were taken up with yield than in the treatment without the deposit (Table 3). The highest uptake of Zn, Cu, Cd and Cr was recorded for the control plant yield, while most Ni and Pb were found in the plant biomass from the treatment with a 10% admixture of bottom sediment.

The assessment of the degree and direction of the translocation of individual elements in plant distinguishes two coefficients of plant sensitivity to heavy metals, i.e. bioaccumulation and translocation coefficient. The value of bioaccumulation coefficient (BC) shows the ability of a plant to absorb components from soil and the size of metal translocation from the soil solution to plant aerial parts. Bioaccumulation coefficient is the ratio of plant heavy metal concentration to its quantity in soil (GRZEBISZ et al.1998). The computed values of bioaccumulation coefficient revealed that maize more easily accumulated Zn, Cd and Cd (the highest values of BC) than Cr, Ni or Pb (Table 4), which evidences considerable mobility of Zn and Cd in comparison with other metals and their relatively easy absorption by plants. Moderate accumulation levels were assessed for zinc, cadmium and copper (BC; 0.1-1), whereas the other metals (BC; 0.01-0.1) produced low BC. While estimating the effect of bottom sediment, it was determined that both its doses added to the soil led to a decrease in Zn, Cu, Cd, Cr and Ni accumulation (5% dose) in maize aerial biomass in comparison with the plants which absorbed the highest amounts (Table 4). It was only the level of lead that rose by 4% (5% of sediment) and 17% (10% sediment) in comparison with the control plants as a result of soil enrichment with bottom sediment. Diminished values of bioaccumulation coefficient in maize may be explained by the fact that bottom sediment admixture to the soil alkalized the soil environment (increasing its pH value), therefore decreasing metal availability to plants. Mobility of the metals in maize was determined using translocation coefficient (TC). This parameter was computed as a ratio of metal content in the aerial parts to its content in roots (JASIEWICZ, ANTONKIEWICZ 2000). In maize, the values of TC coefficient appeared in the following increasing order: Cd < Ni < Pb < Cr < Cu < Zn (Table 4). Our analysis of the TC coefficient values showed that maize roots absorbed the highest quantities of Cd, Ni and Pb. A 5% admixture of bottom sediment caused a decline in this parameter value by 1.5% for zinc, 11% for chromium, 30% for copper and cadmium and 35% for nickel, but 7% increase for lead versus the control

Table 4

Bioaccumulation and translocation coefficient of metals in maize

| Treatment | Bioaccumulation coefficient (BC) | | | | | |
|---|---|---|---|---|---|---|
| | Zn | Cu | Ni | Pb | Cd | Cr |
| Soil without sediment | 0.63 | 0.33 | 0.07 | 0.03 | 0.45 | 0.09 |
| Soil+ 5% sediment | 0.40 | 0.25 | 0.06 | 0.03 | 0.27 | 0.08 |
| Soil +10% sediment | 0.55 | 0.32 | 0.10 | 0.04 | 0.43 | 0.09 |
| Treatment | translocation coefficient (TC) | | | | | |
| | Zn | Cu | Ni | Pb | Cd | Cr |
| Soil without sediment | 0.60 | 0.39 | 0.15 | 0.20 | 0.12 | 0.31 |
| Soil+ 5% sediment | 0.61 | 0.27 | 0.09 | 0.21 | 0.09 | 0.28 |
| Soil +10% sediment | 0.80 | 0.56 | 0.18 | 0.22 | 0.13 | 0.38 |

values. This coefficient reached its highest values for all the analyzed metals when a 10% supplement of bottom sediment was added to the soil, which points to an increased metal mobility in plants under the influence of the applied bottom deposit (Table. 4). The value of the metal translocation coefficient in this treatment increased by 2% for cadmium, 11% for lead,18% for chromium and nickel, 24% for zinc and by over 30% for copper in comparison with the control. WIŚNIOWSKA-KIELIAN and NIEMIEC (2007a) obtained slightly different results. These authors found that bottom deposit added to soil significantly lowered values of metal translocation coefficients in maize. Also ANTONKIEWICZ and LOSAK (2007) revealed a decrease in value of this coefficient in plants as a result of  ash admixture to soil due to the substrate alkalization.

To sum up, extracted sediments which are either neutral or alkaline, have a high content of silt and clay fractions and low heavy metal concentrations may be utilized for improving the properties of light and acid soils (WIŚNIOWSKA-KIELIAN, NIEMIEC 2007ab). The sediment applied in the present research had a high share of silt and clay fractions, alkaline pH and low content of heavy metals, therefore it may be used as an admixture to the above-mentioned soils to improve their productivity. It is commonly know that pH has much influence on metal mobility; the lower pH value, the greater the solubility of individual metals. Another environmentally justifiable method of dredged sediment management is to use it use as structure and soil forming material for soilless systems and wastelands (POPENDA et al. 2007). In the present experiment, the assessment of heavy metal content in maize included the assumption that the maize biomass would be used for production of animal feeds, therefore using threshold limits of heavy metals in plants stated by various authors CURYŁO et al. (1985), KABATA-PENDIAS et al.

(1993) and the *Ordinance of the Minister of Agriculture and Rural Development* on the permissible quantities of undesirable substances in feeds (Dz.U. 2007. Nr 20, poz. 119). The permissible amounts of heavy metals in feeds are as follows: <100 mg Zn, <10 mg Cu, <10 mg Cr, <10 mg Ni, <5 mg Cd and <10 mg Pb $kg^{-1}$ d.m. The assessment of the maize biomass obtained using these threshold levels proved that it met the requirements set for good quality fodder with respect to the contents of all the heavy metals.

## CONCLUSIONS

1. The sediment added to the soil as a 5% dose decreased the content of all the analyzed heavy metals in maize aerial biomass, whereas a 10% admixture increased their content (Cu, Ni, Pb and Cr).

2. The values of bioaccumulation coefficients revealed that an admixture of both doses of bottom sediment led to a decreased accumulation of Zn, Cu, Cd, Cr and Ni (5% dose) in maize aerial biomass. However, under these conditions maize more easily accumulated Zn, Cd and Cu than Cr, Ni or Pb.

3. The values of translocation coefficient showed increased metal mobility in roots to arerial parts under the influence of a 10% bottom sediment admixture to the soil.

4. No excess of the permissible content of heavy metals in plants used as animal forage were found in the maize biomass.

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