E C O L O G I C A L C H E M I S T R Y A N D E N G I N E E R I N G A

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EFFECT OF ORGANIC WASTES ON ZINC AND LEAD ACCUMULATION IN OAT BIOMASS

WPŁYW ODPADÓW ORGANICZNYCH NA AKUMULACJĘ CYNKU I OŁOWIU W BIOMASIE OWSA

Abstract: The studies on the effect of organic wastes on zinc and lead content in oat were conducted in 2006 as a pot experiment. Mineral salts, farmyard manure, compost, municipal and industrial sludge at two fertilization levels were used in the experiment.

The highest zinc content in plants and its uptake by oat was found in the treatments fertilized with industrial sewage sludge, whereas Pb contents were the biggest in the compost and municipal sewage sludge treatments. The analysis of bioaccumulation coefficient value shows that the aboveground oat biomass accumulated bigger quantities of Zn than Pb, whereas the roots to a greater extent limited lead translocation in the plant. No exceeded lead contents according to plant assessment in view of their fodder usability were detected in oat. The plants revealed over the norm zinc content.

Keywords: farmyard manure, compost, municipal and industrial sewage sludge, zinc, lead, oat

Current reduction of animal organic wastes production makes necessary using other organic wastes (composts or sewage sludges) as unconventional fertilizers for soil and crop treatment [1]. According to Siuta [2] and Mazur [1] it is both environmentally and economically justified. These materials, while increasing soil abundance in humus, macro- and microelements, also improve the soil biological activity and reveal multidirectional effect on the soil and plant [1, 3]. However, usefulness of some wastes (sewage sludge) in agriculture may be limited because of too high contents of heavy metals or other harmful substances [4, 5]. Considering the sanitary aspect, sewage sludges may be decontaminated by means of their mixing with calcium oxide or composting with plant materials. Composting allows for considerable decreasing of heavy metal contents in the sludge in comparison with their initial values [6]. While assessing organic waste usefulness for fertilization one should also consider the response of fertilized crops, heavy metal accumulation in their biomass and their destination [7].

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The investigations aimed at an assessment of the consequent effect of various organic wastes on the content and uptake of zinc and lead by oat.

Material and methods

The studies on the effect of organic wastes on zinc and lead content in oat were conducted as pot experiment in 2006. The paper presents the results obtained for oat cultivated in the third year of the experiment conducted on the soil with granulometric structure of weakly loamy sand, pH_{KCl} = 4.66 and organic matter content 19.3 g · kg^{-1}. Moreover, the soil revealed a low content of bioavailable phosphorus and potassium, elevated zinc content and natural content of lead [8]. The experimental design comprised 11 treatments differing with the dose and kind of the supplied fertilizers. The sources of nutrients for oat were mineral salts (NH_4NO_3, KH_2PO_4, KCl), farmyard manure, municipal and industrial sewage sludge. Chemical composition of the organic materials was given in Table 1. Two fertilization levels were taken into consideration: the first level: 0.30 g N, 0.11 g P and 0.26 g K · pot^{-1} (5 kg of soil) and the second level – double amounts of NPK. The materials and organic wastes were applied in the first year of the experiment under maize and their doses were established on the basis of nitrogen fertilization [9]. Compost of plant wastes was manufactured by Ekokonsorcjum Efekt Ltd. Enterprise in Krakow. Sludges from municipal and industrial sewage originated from "Empos" municipal-industrial sewage treatment plant in Oswiecim. No exceeded permissible norms of heavy metal contents were assessed in the organic wastes, therefore they met the requirements for fertilizers used in agriculture (Table 1) [10].

Table 1

Chemical composition of organic materials

Chemical composition		Farmyard manure	Compost	Municipal sludge	Industrial sludge
Dry mas	[%]	14.56	54.72	18.81	21.84
Organic mater	[g · kg^{-1} d.m.]	855.3	437.3	640.4	482.8
Zinc	[mg · kg^{-1} d.m.]	115.0	228.4	741.6	722.0
Lead		2.37	16.15	38.76	46.25

Zinc and lead contents in the plant material (the shoots and roots) were assessed following the dry mineralization and the ash dissolving in HNO_3 (1:3). Total zinc and lead contents in the soil were determined after hot mineralization in HNO_3 and $HClO_4$ (3:2) mixture. Concentrations of the analyzed elements were assessed in the obtained solutions using inductively coupled plasma emission atomic spectrophotometry (ICP-EAS). Zinc and lead uptake was computed and their bioaccumulation and translocation coefficients in the test plant. The results were elaborated statistically using one-way ANOVA and Tukey test at significance level α = 0.05 by means of Statistica 7.0 programme.

Results

Zinc and lead content in plant was diversified depending on the plant part and experimental treatment (Table 2).

Table 2

The content of zinc and lead in oats [mg · kg^{-1}d.m.]

Treatments		Shoots		Roots	
		Zinc	Lead	Zinc	Lead
Without fertilization		103.65	1.07^{bcd}**	197.70^{ab}	4.75^{a}
NPK	1*	124.17	0.64^{ab}	199.70^{ab}	6.61^{ab}
	2	130.45	0.77^{abc}	200.12^{ab}	5.58^{ab}
Farmyard manure	1	117.12	0.82^{abc}	206.32^{ab}	8.10^{ab}
	2	148.27	1.19^{cde}	239.80^{bc}	9.19^{ab}
Compost	1	107.95	1.21^{cde}	170.53^{a}	9.97^{ab}
	2	120.62	1.46^{de}	205.17^{ab}	8.33^{ab}
Municipal sludge	1	138.93	1.56^{f}	253.38^{ab}	10.36^{b}
	2	139.29	0.56^{a}	295.87^{bc}	8.73^{ab}
Industrial sludge	1	137.89	0.50^{a}	335.28^{c}	9.34^{ab}
	2	151.80	0.79^{abc}	412.32^{d}	8.34^{ab}
$LSD_{0.05}$		n.s.***	0.25	34.15	2.98

Explanation for Tables 2–4: * dose; ** homogeneous groups according to the Tukey test; $\alpha = 0.05$; *** n.s. – not significant.

Zinc concentrations in oat in comparison with lead were relatively high, which resulted from introducing considerable amounts of the metal with the organic wastes (Table 1) but also with highly active uptake of his element by the plants. The roots contained between twice and thrice greater quantities of zinc than the aboveground parts depending on the experimental treatment. The organic materials caused an increase in zinc content in the aboveground plant biomass in relation to the control plants, but the differences were statistically insignificant. A notable effect of the dose and kind of organic material on zinc content in the test plant roots was registered (Table 2). The largest zinc content both in oat shoots and roots was registered on the treatment where a double dose of industrial sludge was applied. On this treatment oat contained almost 46 % greater quantities of zinc (aboveground parts) and 108 % (roots) in comparison with the control. The smallest amounts of this metal were assessed in the aerial parts and roots obtained from the object fertilized with a single dose of compost. It may be explained by dissolving of zinc, because plants fertilized with compost produced the largest root biomass [11]. Application of the second fertilization level caused an increase in zinc content in plant. On the other hand, depending on the kind of organic material, zinc content in oat may be ordered in the following descending sequence: industrial sewage sludge > municipal sewage sludge farmyard manure > NPK > compost.

The discussed experiment demonstrated a significant effect of NPK and organic materials on Pb contents in oat (Table 2). Similarly as in case of zinc, oat roots accumulated between 4 and 19 times greater quantities of this metal than the shoots. The obtained results confirm the thesis that Pb becomes accumulated in relatively big quantities on the root surface, which is a mechanism limiting this metal uptake from the soil [12, 13]. Additionally all organic materials and NPK caused an average 78 % increase in Pb content in oat roots in comparison with the control plants. Significantly the greatest lead concentrations were registered in the aboveground biomass and in roots of oat on the treatment receiving a single dose of municipal sewage sludge. In comparison with the unfertilized plants on this treatment, oat contained by over once (aboveground parts) and twice (roots) bigger amounts of lead. On organic treatments the smallest lead content in the oat aboveground biomass was detected after the application of a single dose of industrial sewage sludge and a double dose of municipal sewage sludge, whereas in roots on the treatments receiving a single farmyard manure dose. Sewage sludges led to a decrease in Pb level in the aboveground biomass by 43 % in relation to the control plants. Lead contents in oat may be ordered as follows: compost > municipal sewage sludge ≈ farmyard manure > NPK > industrial sewage sludge (shoots) and municipal sewage sludge > compost > industrial sewage sludge ? farmyard manure > NPK.

Table 3

Uptake of heavy metals by oats [mg · pot^{-1}]

Treatments		Shoots		Roots	
		Zinc	Lead	Zinc	Lead
Without fertilization		0.78^{a}**	0.008^{a}	0.23^{a}	0.006^{a}
NPK	1*	1.87^{ab}	0.010^{ab}	0.35^{abc}	0.012^{ab}
	2	2.04^{abc}	0.010^{ab}	0.26^{ab}	0.008^{ab}
Farmyard manure	1	2.52^{bcd}	0.018^{bcd}	0.39^{abcd}	0.015^{ab}
	2	3.67^{cd}	0.029^{ef}	0.52^{abcd}	0.020^{ab}
Compost	1	2.25^{abc}	0.025^{de}	0.49^{abcd}	0.020^{ab}
	2	2.46^{bcd}	0.031^{ef}	0.40^{abcd}	0.024^{b}
Municipal sludge	1	2.99^{bcd}	0.014^{abc}	0.61^{bcd}	0.019^{ab}
	2	3.55^{bcd}	0.033^{e}	0.63^{cd}	0.025^{b}
Industrial sludge	1	2.99^{bcd}	0.011^{ab}	0.73^{de}	0.020^{ab}
	2	3.97^{d}	0.021^{cd}	1.02^{f}	0.021^{ab}
$LSD_{0.05}$		0.095	0.005	0.20	0.01

The quantity of heavy metals absorbed with the plant biomass is a resultant of the values of obtained yields and their contents of these metals [14]. The absorbed quantities are also influenced by the soil properties, the element form (ion or complex), species features and the plant organ [15]. Considering the share of individual oat parts in total zinc uptake it was found that the aboveground oat biomass took up the biggest quantities of this metal (Table 3).

The aerial biomass accumulated between 77 % and 88 % of the total absorbed amount of Zn, whereas the roots between 11 % and 23 % of this metal. For lead it was found that both oat aboveground parts and roots absorbed comparable amounts of this metal (Table 3). Depending on the experimental treatment, between 35 % and 59 % of Pb was taken up with the aerial biomass, whereas between 41 % and 65 % with roots. On the other hand, the analysis of heavy metal uptake depending on the dose and kind of organic material revealed significant increase in zinc and lead uptake by oat on fertilized treatments in comparison with unfertilized plants. The greatest aggregate heavy metal uptake by oat shoots and roots was determined on the treatments with residual effect of industrial sewage sludge (zinc) and municipal sewage sludge (lead) applied in a double dose. The lowest zinc uptake among the treatments with a consequent effect of fertilizers and organic materials was registered on the treatment with compost, whereas lead uptake on the treatment with industrial sewage sludge. Depending on the experimental treatment an aggregate zinc uptake by oat may be placed in the following descending order: industrial sewage sludge > municipal sewage sludge > farmyard manure > compost > NPK and for lead: compost ? municipal sewage sludge > farmyard manure ≈ industrial sewage sludge > NPK.

Bioaccumulation and translocation coefficients were used for the assessment of the degree and direction of heavy metal movement in plants. The value of bioaccumulation coefficient reflects plant ability to absorb the components from soil. This parameter is a ratio of metal contents in the aerial plant parts to its soil contents [16, 17].

Computed bioaccumulation coefficient values for zinc ranged from 1.61 to 2.38 and for lead from 0.02 to 0.06 (Table 4). These values indicate that oat aboveground biomass more easily accumulated zinc than lead. Additionally they evidence a considerable Zn mobility in comparison with Pb and its relatively easy uptake by plants [15].

Table 4

Bioaccumulation and translocation coefficient of Zn and Pb in oats

Treatments		Bioaccumulation coefficient		Translocation coefficient	
		Zinc	Lead	Zinc	Lead
Without fertilization		1.56	0.04	0.53	0.23
NPK	1*	1.85	0.02	0.62	0.10
	2	2.38	0.03	0.99	0.14
Farmyard manure	1	1.80	0.03	0.57	0.10
	2	2.27	0.05	0.62	0.13
Compost	1	1.61	0.04	0.54	0.12
	2	1.88	0.06	0.71	0.17
Municipal sludge	1	2.19	0.02	0.50	0.06
	2	2.05	0.06	0.47	0.15
Industrial sludge	1	2.01	0.02	0.41	0.05
	2	2.13	0.03	0.37	0.10

Intensive degree of accumulation was registered for zinc (BC; 1–10), whereas weak for lead (BC; 0.01–0.1). The highest values of zinc bioaccumulation coefficient were estimated for the plants fertilized with a double NPK dose, the lowest for the control plats, therefore all applied fertilizer components caused an increase in Zn mobility on average by 32 % in relation to the unfertilized treatment (Table 4). Increasing Zn mobility in oats on fertilized treatments may be ascribed to the fact that the applied fertilizers and organic wastes acidified the soil environment and therefore increased Zn availability to plants. For lead the highest value of bioaccumulation coefficient was determined for the treatments with the consequent effect of a double compost and municipal sewage sludge dose (Table 4). On the other hand, application of a single dose of farmyard manure, compost, municipal sewage sludge, both NPK doses and industrial sewage sludge resulted in a decrease in this coefficient value on average by 36 % in the test plant in comparison with the control plants. In the investigations conducted by Jablonska and Ceglarek et al [18] the plants (cabbage, beetroots and lettuce) fertilized organically also revealed lower value of lead accumulation coefficient than the plants from the unfertilized treatment.

Metal mobility in oat was determined using translocation coefficient. This parameter was computed as a ratio of metal contents in oat aerial parts to its content in the roots [19]. The values of translocation coefficients fell within the range of 0.37–0.99 for Zn and 0.01–0.17 for Pb (Table 4). The analysis of translocation coefficient values shows that oat roots absorbed greater amounts of lead than zinc. Values of translocation coefficient indicate a decrease in Zn mobility from the roots to the aboveground parts on the treatments fertilized with municipal and industrial sewage sludge. All applied fertilizer materials reduced lead mobility from the roots to the aerial parts of plant and the value of translocation coefficient for lead was on average by 50 % lower on the fertilized treatments than on the control. The lowest values of lead translocation coefficient were registered on the treatments with the residual effect of a single sewage sludge dose.

Discussion

Utilization of organic waste materials for crop fertilization may positively affect their chemical composition but also cause an excessive accumulation of heavy metals in plants. Zinc and lead absorbed in excessive quantities may cause the stress conditions for plants and reveal high toxicity. It has been commonly known that individual heavy metals accumulate in various degrees in different plant parts. In the opinion of Gebski et al [20] zinc may accumulate simultaneously in the roots and shoots, whereas lead cumulates mainly in roots. The results confirming this dependency were obtained also in the presented experiments while analyzing bioaccumulation and translocation coefficients. In the discussed experiment the consequent effect of industrial sewage sludge led to a relatively big zinc content and uptake with the yield of the test plant, whereas for lead the similar effect was noted for compost and municipal sewage sludge fertilization. Similar dependencies were determined for ryegrass in the second year of the presented research [21]. The assessment of heavy metal content in oat was based on potential utilization of the produced biomass for fodder, using their limit content: < 100 mg Zn and < 10 mg Pb $\cdot$ kg^{-1} d.m. [22, 23]. Assessing the obtained aboveground oat biomass according to this criterion it was found that it meets the requirements considering lead content. In case of zinc, the plants from all treatments revealed over the norm its content (Table 2).

As stated by Jakubus [24] and Krzywy et al [25] environmental utilization of organic wastes is an efficient method of their disposal and the concept of their management in agriculture has the best perspective of development. It is particularly important in case of sewage sludges because a growing number of sewage treatment plants face the problem of the management of considerable waste amounts, whereas storage of these materials requires considerable space [5]. Moreover, agricultural management of organic materials is of extreme environmental-ecological importance allowing for reducing the use of mineral fertilizers, which ecological effects are less favourable than organic fertilizer effects [26].

Conclusions

1. The highest content and uptake of zinc by oat were stated on treatments with industrial sewage sludge, whereas lead uptake was the highest on the compost and municipal sewage sludge treatments.
2. Tested organic wastes cause an increase in zinc bioacummulation coefficient value. For lead the decrease in this parameter value in oat was the result of application of a majority of organic wastes.
3. All applied organic materials limited lead transport from plant roots to the shoots and for zinc such effect was registered for the application of industrial and municipal sewage sludge.
4. No exceeded admissible values of lead content, used for plant assessment in view of their usability for fodder, were registered in oat. The plants revealed over the norm zinc contents.

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WPŁYW ODPADÓW ORGANICZNYCH NA AKUMULACJĘ CYNKU I OŁOWIU W BIOMASIE OWSA

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Abstrakt: Badania nad wpływem odpadów organicznych na zawartości cynku i ołowiu w owsie przeprowadzono w 2006 r. w doświadczeniu wazonowym. W doświadczeniu użyto sole mineralne, obornik, kompost oraz osady ściekowe komunalny i przemysłowy, które zastosowano w dwóch poziomach nawożenia.

Największa zawartości cynku w roślinach i jego pobranie przez owies została stwierdzone w obiektach nawożonych przemysłowym osadem ściekowym, podczas gdy zawartości Pb były największe w roślinach z obiektów z dodatkiem kompostu i komunalnego osadu ściekowego. Analiza wartości współczynników bioakumulacji i translokacji wykazała, że nadziemna biomasa owsa gromadziła większe ilości Zn niż Pb, podczas gdy korzenie w większym zakresie ograniczały przemieszczanie się ołowiu w roślinie.

Nie stwierdzono przekroczenia zawartości ołowiu w roślinach owsa ocenianej według kryteriów użyteczności paszowej, natomiast rośliny zawierały ponadnormatywne ilości cynku.

Słowa kluczowe: obornik, kompost, komunalny i przemysłowy osad ściekowy, cynk, ołów, owies