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Usefulness of rock dust waste for the remediation of zinc contaminated soils[1]

Przydatność odpadowego pyłu skalnego do remediacji gleb zanieczyszczonych cynkiem

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Abstract

The aim of this study was to check whether the addition of waste rock dust to the soil contaminated with zinc will improve the yield of reed canary grass and reduce excessive amounts of zinc in its biomass. The study was carried out in the micro-plots made of concrete, as a two-factorial experiment, in a randomized complete block design, with four replicates. The first factor of the experiment was the level of soil contamination with zinc: 1) Zn_0 – the soil with natural Zn concentration; 2) Zn_1 – 200; 3) Zn_2 – 400; 4) Zn_3 – 800 mg/kg soil. The second factor was the level of remediation: 1) control, without remediation, 2) with remediation (rock dust applied at the rate 3 kg•m^{-2}). The results of the study indicate that application of waste rock dust can improve the conditions of reed canary grass growth in the soil contaminated with zinc. At the highest level of contamination (Zn_3), soil amendment with rock dust resulted in increased yields of reed canary grass dry matter, in two crops, by 136 and 176%, respectively, as compared with corresponding control objects without dust addition. At the same time, the concentrations of zinc in the plants grown in the soil amended with dust were about 16% lower, and the soluble forms of this element in soil, determined in extraction with 1 mol HCl•dm^{-3}, were about 25% lower, as compared with control plots.

Streszczenie

Celem doświadczenia było sprawdzenie czy dodatek odpadowego pyłu skalnego do gleby zanieczyszczonej cynkiem wpłynie na poprawę plonowania mozgi trzcinowatej oraz na zmniejszenie w niej nadmiernych zawartości cynku. Badania przeprowadzono w betonowych mikropoletkach w układzie kompletnej randomizacji, jako dwuczynnikowe, w czterech powtórzeniach. Pierwszy czynnik stanowił poziom zanieczyszczenia gleby cynkiem: 1) Zn_0 – gleba z naturalną zawartością Zn; 2) Zn_1 –200; 3) Zn_2 –400; 4) Zn_3 –800 mg/kg gleby. Drugim czynnikiem był poziom remediacji: 1) kontrola bez remediacji; 2) remediacja (pył skalny w dawce 3 kg•m^{-2}). Wyniki badań wskazują, że zastosowanie odpadowego pyłu skalnego może poprawić warunki wzrostu mozgi trzcinowatej na glebie zanieczyszczonej cynkiem. Przy największym poziomie zanieczyszczenia (Zn_3) dodatek pyłu skalnego do gleby spowodował wzrost plonów suchej masy mozgi w obu pokosach o 136 i 176% w stosunku analogicznego obiektu kontrolnego, bez dodatku pyłu. Jednocześnie stwierdzono około 16% niższą koncentrację cynku w roślinach rosnących na glebie z dodatkiem pyłu oraz około 25% niższą zawartość rozpuszczalnej formy tego pierwiastka w glebie ekstrahowanej 1mol HCl•dm^{-3}.

1. INTRODUCTION

Zinc is an essential element occurring in the environment which plays important metabolic functions in living organisms. However, its excessive content in the soil can result in abnormalities in the uptake and transport of nutrients necessary for proper growth and development of plants. Also, its too high accumulation in aerial parts, often used for the production of feed and food, is a potential threat to human and animal health [Baran and al. 2008]. Although several studies indicate significant tolerance of plants to high zinc content in the soil, however, the phytotoxicity of this element is associated with a number of factors such as the physicochemical properties of the soil, or plant species [Baran, Jasiewicz 2009].

The problem of soil contamination with zinc in Poland exists locally, mainly in industrialized areas. The reason of contamination of agricultural soils with this element, besides industrial emissions, can be due to the wrong fertilization, for example through the incompetent use of waste of anthropogenic origin. The current regulations require the need for continuous monitoring of metal contaminations in the soil as regards the quality standards of soil and land [Regulation 2002b]. In case of exceeding the permissible levels of zinc, at least a dozen methods of soil remediation can be used. However, when choosing the right method, its effectiveness, the degree of harm to the environment and the financial side of the procedure need to be taken into consideration. One of the cheaper, yet effective methods of remediation is to improve soil's physical and chemical properties which determine the mobility of metals in the soil environment. The procedure of liming which increases soil pH, as well as the introduction of materials rich in organic matter or in clay minerals improving its sorption properties, may help to reduce the mobility of zinc in soil and its availability to plants [Karczewska, Kabbalah 2010]. In order to increase the sorption capacity of the soil, a variety of organic or mineral waste materials can be used which should be properly disposed of in accordance with applicable legal standards. After suitable treatment, they can be used both for fertilization and recultivation purposes [Siuta 2007].

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The use of materials rich in organic matter, or based on brown coal or ashes from the combustion of hard coal, resulted in limiting of the uptake of Zn, Pb and Cd in some crops and grasses [Kwiatkowska–Raspberry, Maciejewska 2009, Antonkiewicz 2009] and had the effect on limiting the mobility of trace elements in the soil, therefore being an alternative to the dolomitic lime [Bielińska, Aries 2009].
Another type of additives which improve soil physical and chemical properties can be dust rock (stone) obtained as a by-product of mechanical processing of raw rock, mainly basalt and granite. Waste in the form of sludge, obtained as a result of cutting and polishing of rock, is subjected to dehydration in the settling tanks. The dried waste deposited in landfills is a major environmental problem and requires proper planning, because its storage is associated with increasingly environmental charges.
The aim of this study was to determine whether the addition of dust rock waste into soil contaminated with zinc will improve crop yields and the reduction in the excess of zinc, and thus will be useful for the remediation of soil contaminated by this element.

2. MATERIALS AND METHODS

The studies with the use of the waste rock dust on the soil contaminated with zinc were conducted on concrete microplots with the dimensions of 1 × 1 m. The experiment was established at the Experimental Station IUNG – PIB in Baborówko near Poznan in the system complete of randomization as a two-factor, in four replications. The first factor was the level of soil contamination with zinc: 1) Zn_0 – soil with natural Zn content, 2) Zn_1 – 200, 3) Zn_2 – 400, 4) Zn_3 – 800 mg/kg of soil. The second factor was the level of remediation: 1) control without remediation, 2) with remediation (rock dust at 3 $kg \cdot m^{-2}$). Zinc was introduced into the soil in summer 2007 in the form of sulphate, which was previously dissolved in water and filled into plots with a watering can, and then mixed with a 40 cm layer of soil. In autumn 2010, the contaminated soil was evenly sprinkled with rock dust and dug to the depth of 20 cm.
The tested waste rock, for the most part granite one, originating from plants located near Dzierżoniów in Lower Silesia, was characterized by an alkaline reaction and a low content of toxic elements (Table 1).

Table 1. Basic physicochemical properties of waste rock-powder.

pH 1mol KCl dm^{-3}	Zawartość – Content ($g \cdot kg^{-1}$)						Zawartość – Content ($mg \cdot kg^{-1}$)						
	s. m. d. m.	SiO_2	P_2O_5	K_2O	CaO	MgO	Cr	Zn	Cd	Cu	Ni	Pb	Hg
8,0	991,6	758	3,2	9,9	28,7	3,9	29 (100)	179 (300)*	< 0,5 (1)*	42,6 (100)*	14,3 (50)*	< 20 (100)*	< 0,01 (1)*

* Permissible quantities of contaminants according to the Decision of the Commission of the European Communities (No C(2006) 5369).

The experiment was established on loamy sand with low class of humus content (C org. = 0.85%) and acidic reaction (pH = 5.3). Reed canary grass was used a test plant. It was seeded at the amount of 2 g/plot. NPK fertilization, which is typical for grass in the field cultivation, was applied. Two cuts of reed canary grass were collected and determined for dry matter yield. In the samples taken from each cut, Zn content was determined by flame atomic absorption spectrometry (F-AAS), after prior dry mineralization of the material. Soil samples were collected in the spring of 2011 before sowing of reed canary grass, which were determined for the content of Zn by flame atomic absorption spectrometry (F-AAS), using 1 M HCl as an extraction solution. Also, granulometric composition of the soil was determined by asymetric – sieve method, the pH – by potentiometry in aqueous KCl concentration of $1 mol \cdot dm^{-3}$, and the organic carbon content by Tiurin's method.
The results of the yields were statistically analyzed using the AWAR program.

3. RESULTS AND DISCUSSION

The excessive zinc content of the soil resulted in a significant decrease in dry matter yields of reed canary grass, depending on the degree of contamination of the soil with this element (Table 2). The lowest level of pollution (Zn_1) did not initially cause a negative reaction of plants. In the first cut, statistically unproven 7% increase in yields was found, which may indicate insufficient natural Zinc content in the soil for this plant and fertilizing action of the used element. However, in the second cut, 20% lower yield was collected with respect to the object of the natural content of zinc (Zn_0). At the next level of contamination (Zn_2) in the first and second cut, the obtained yield was by 32-35% lower than in the control object Zn_0, and at the Zn_3 level, the reduction in yields was very high and amounted to more than 80% in both cuts.

Table 2. Dry matter yield of reed canary grass in $g \cdot m^{-2}$.

II czynnik: Remediacja II^nd factor: Remediaton	I pokos – I^st cut				II pokos – II^nd cut				Suma – Total			
	I czynnik: stopnie zanieczyszczenia – I^st faktor: contamination rates											
	Zn_0	Zn_1	Zn_2	Zn_3	Zn_0	Zn_1	Zn_2	Zn_3	Zn_0	Zn_1	Zn_2	Zn_3
Kontrola Control	326,8	349,5	223,0	62,50	362,2	286,8	236,7	62,5	689,0	636,2	459,8	125,0
Pył skalny Rock-powder	297,8	305,8	253,0	147,8	331,5	298,2	262,0	172,8	629,2	604,0	515,0	320,5
NIR LSD II/I	34,90				38,23				64,66			
NIR LSD I/II	46,62				51,07				86,36			

The research by Korzeniowska et al. [2011] shows that reed canary grass is not suitable for phytostabilization of zinc contaminated areas. It showed a significantly lower tolerance to this element than willow and corn. Paschke et al. [2000] suggest that the species of grasses are more resistant to the phytotoxic action of zinc than crops. The authors determined the toxicity thresholds for five grass species, which are commonly used in reclamation activities in the western part of the United States.

The results of own research show that the use of waste rock dust as a remedial material can improve the growth of reed canary grass on soil contaminated with zinc. However, there was a significant interaction effect between remedial effect of waste rock dust and the level of soil contamination with zinc. At the Zn_1 level, the application of dust to the soil decreased the yield of reed canary grass in the first cut by 13% compared to the corresponding control object. The concentration of zinc in the dry matter of reed canary grass on the object with rock dust was slightly higher than on the control object without dust (Table 3).

Table 3. Zinc content in plant dry matter in mg • kg^{-1}.

II czynnik: Remediacja IInd factor: Remediaton	I pokos – Ist cut				II pokos – IInd cut				Średnia z pokosów – Mean of cuts			
	I czynnik: stopnie zanieczyszczenia – Ist faktor: contamination rates											
	Zn_0	Zn_1	Zn_2	Zn_3	Zn_0	Zn_1	Zn_2	Zn_3	Zn_0	Zn_1	Zn_2	Zn_3
Kontrola Control	55	719	1568	2997	58	649	1188	2328	56	684	1378	2662
Pył skalny Rock-powder	69	853	1546	2526	69	724	1187	1962	69	788	1366	2244

Perhaps, the reason for that was a relatively high, but acceptable content of this element in the waste rock (Table 1), which had some role in increasing the pool of this element for plants. But this was not confirmed by the analysis of the soil at the lowest degree of soil contamination with zinc. The content of soluble zinc in 1 mol HCl was lower here than for the corresponding object without rock dust (Table 4).

Table 4. The soil zinc content extracted in 1 mol HCl • dcm^{-3} (mg • kg^{-1}).

II czynnik: remediacja IInd factor: remediaton	I czynnik: stopnie zanieczyszczenia – Ist faktor: contamination rates			
	Zn_0	Zn_1	Zn_2	Zn_3
Kontrola Control	16,6	332	528	600
Pył skalny Rock-powder	17,2	248	408	443

At the average level of soil contamination (Zn_2), there was no remedial action of the studied waste. Both the dry matter yield and zinc content in the dry matter was comparable to the control, even though on the object with the applied dust, the content of soluble zinc in the soil was by 22% lower. Only at the highest soil contamination with zinc (Zn_3), the addition of rock dust to the soil resulted in higher yields of dry matter in reed canary grass in the two cuts by 136 and 176% compared to the corresponding control object without the addition of dust. At the same time, there was by about 16% lower concentration of zinc in plants grown in soil with the addition of rock dust and approximately by 25% lower content of this element in the soil.

The use of rock dust depends, among other things, on their mineralogical and chemical composition and granulation. Gałka et al. [2011] pointed out to the possibility of using this material for remediation of soils contaminated with heavy metals or as a volumetric filler or additive to correct the properties of contaminated yields. Own study shows that the application of waste rock dust limited the availability of zinc for plants, which resulted in a decrease of excessive amounts of the element and the increase in yields of reed canary grass. In the studies of Baran et al. [1995], the application of rock dust, rich in clay minerals, to the soil contaminated with lead and zinc significantly reduced solubility of the metals in the soil, in particular zinc (up to 14%). For the soils contaminated with zinc, copper and nickel, the use of rock dust limited negative effects of these metals on the growth of mustard [Stanisławska-Glubiak et al. 2009].

Apart from the remedial action, some rock dusts exhibit fertilizing action. Basalt meal can be used as fertilizer microelement because of the diversity occurring in these trace elements [Zagożdżon 2008], and the residual granite dust as a potassium fertilizer. Increasing contents of potassium content in the soil (up to 300%) as a result of the dissolution of granite, resulted in an increase in wheat yields on the objects with the applied rock material [Hinsinger et al. 1996].

4. CONCLUSIONS

1. The tested waste material in the form of dehydrated stone sludge (rock dust) resulted in improving the yielding efficiency of the soil contaminated with zinc, which was particularly evident at significant soil contaminations with this element.
2. The addition of rock dust to the soil caused a decrease in the zinc content of reed canary grass, and in the soil itself, which indicates the reduction of the mobility of this element in the soil and its availability to the plants.
3. The used waste rock dust can also be used in procedures for the remediation of soils contaminated with zinc.

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