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The usefulness of the rock dust for the remediation of soils contaminated with nickel[1]

Przydatność pyłu kamiennego do remediacji gleb zanieczyszczonych niklem

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Abstract

The purpose of this research was to examine whether the addition of waste rock dust to light soil contaminated with nickel will increase the yields of cultivated plants and reduce their excessive nickel content. The research was conducted in concrete microplots of 1 m^2 dimension in the complete randomisation system, as a two-factor experiment in four replications. The first factor was the level of soil contamination: (1) Ni_0 – soil with natural Ni content; (2) Ni_1 – 100; (3) Ni_2 – 150 and (4) Ni_3 – 270 mg·kg^{-1} of the soil. The second factor was the level of remediation: (1) control without remediation and (2) rock dust at a dose of 3 kg·m^{-2}. The test results indicate that the use of waste rock dust can improve growth conditions of reed canary grass on the soil contaminated with nickel, in the first year of its cultivation. Addition of rock dust to the soil contaminated with nickel 150 mg·kg^{-1} caused an increase in tolerance of reed canary grass to nickel (tolerance index) from 0.55 to 0.77.
There was an increase in the yield of biomass of aerial parts and a decrease in the concentration of nickel in plants growing in soils with the addition of dust.

Streszczenie

Celem badań było sprawdzenie, czy dodatek odpadowego pyłu skalnego do gleby lekkiej zanieczyszczonej niklem, wpłynie na poprawę plonowania rośliny uprawnej oraz na zmniejszenie w niej nadmiernych zawartości niklu. Badania przeprowadzono w betonowych mikropoletkach o powierzchni 1 m^2 w układzie kompletnej randomizacji, jako dwuczynnikowe, w czterech powtórzeniach. Pierwszy czynnik stanowił poziom zanieczyszczenia gleby niklem: 1) Ni_0 – gleba z naturalną zawartością Ni; 2) Ni_1 – 100; 3) Ni_2 – 150; 4) Ni_3 – 270 mg·kg^{-1} gleby. Drugim czynnikiem był poziom remediacji: 1) kontrola bez remediacji 2) pył kamienny w dawce 3 kg·m^{-2}. Wyniki badań wskazują, że zastosowanie odpadowego pyłu skalnego może poprawić warunki wzrostu mozgi trzcinowatej na glebie zanieczyszczonej niklem, w pierwszym roku jej uprawy. Przy zanieczyszczeniu gleby niklem 150 kg mg·$^{-1}$ dodatek pyłu kamiennego do gleby spowodował wzrost tolerancji mozgi na nikiel (tolerance index) z 0.55 do 0.77. Stwierdzono wzrost plonu biomasy części nadziemnej oraz obniżenie koncentracji niklu w roślinach rosnących na glebie z dodatkiem pyłu.

1. INTRODUCTION

Among heavy metals, nickel is characterised by a high mobility in the environment, and its uptake by plants is regulated by both soil factors and characteristics of the plants. In the soil, nickel is generally associated with organic matter, while in mineral soils, it is absorbed by iron and manganese hydroxides. These factors together with the soil pH affect the solubility of this element in the soil, and hence its availability to plants [Domańska 2009].
Nickel is required for the proper conduct of physiological processes in plants, animals and micro-organisms. It is a component of many enzymes (e.g. ureases, hydrogenases) and also activates some metabolic enzymes that are involved in nitrogen-fixation [Kabata-Pendias & Szteke 2012]. On the other hand, excessive amount of this element in the soil negatively affects yielding and chemical composition of plants. It limits the functions of many enzymes, disturbs the process of photosynthesis, and as a result, causes an overall chlorosis, damage to the roots, and a decrease in the uptake and transportation of nutrients to aerial parts of the plants [Kuziemska & Kalembasa 2010; Spiak 1993]. The presence of nickel in soils is associated with its presence in the source rock, though anthropogenic sources also play an important role. Owing to the frequent use of this element in a wide range of industries, it is easily deposited in the soil. This creates a risk of its toxic effects on plants and soil environment. Taking into account the frequent occurrence of acidification of soils, it is necessary to control the nickel content in the soil and apply appropriate remediation treatments. An effective way of restricting the mobility of heavy metals in soil environment is to improve the physicochemical properties of the soil. Liming of soil, as well as the application of materials rich organic matter or in clay minerals, cause that the mobility of nickel in soil and its availability to plants can be reduced. Rock dust which is a by-product of mechanical treatment of rock materials may affect the physicochemical properties of soils and also has some remediatory properties [Siuta, 2007; Stanisławska-Glubiak, Korzeniowska & Gałka 2009; Karczewska & Kabała 2010; Gałka et al., 2011].
The aim of the study was to verify whether the addition of waste rock dust to the soil contaminated with nickel will improve yields of the cultivated plants and reduce the excessive content of this element.

[1]This work has been prepared as a part of task 2.6 in the IUNG-PIB long-term programme.

2. MATERIALS AND METHODS

In the experimental Station of IUNG-PIB in Baborówko near Poznań, a 2-year microplot experiment with waste rock dust was conducted on the soil contaminated with nickel. Concrete-framed microplots, located below ground level with the dimensions of 1×1×1 m, were filled with soil of granulometric composition of clay sand an acidic pH (Table 1).

The research was conducted in the system of complete randomisation, as a two-factor experiment, in four replications. The first factor was the level of contamination of the soil with nickel. The soil in the layer of 0–30 cm was simulatively contaminated according to the following schedule: (1) Ni_0 – soil with natural Ni content; (2) Ni_1 – 100; (3) Ni_2 – 150; (4) Ni_3 – 270 mg•kg^{-1} of the soil.

Table 1. Some physicochemical properties of the top layer of the soil (0—30 cm)

pH (KCl)	C org.	SF I	SF II	SF III	P_2O_5	K_2O	Mg	Ni
	%				mg•kg^{-1}			
5.2	0.87	80	14	6	167	66	42	8.0

SF I, fraction 2.00–0.05 mm; SF II, fraction 0.05–0.002; SF III, fraction <0.002 mm.

The second factor was the level of remediation: (1) control without remediation and (2) rock dust at a dose of 3 kg•m^{-2}. Nickel was applied into the soil in the summer of 2007 in the form of nickel sulphate (VI), which after having been dissolved in water was spilled onto the plots using watering cans and mixed with 30-cm soil layer. In the autumn of 2010, the contaminated soil was evenly sprinkled with rock dust and turned to the depth of 20 cm. Waste rock dust, mostly granite one, which predominantly came from stone masonry plants located near Dzierżoniow in Lower Silesia, was characterised by a low content of heavy metals (Table 2).

The test plant was reed canary grass, which was seeded in the spring of 2011 at the amount of 2 g/plot and was cultivated for 2 years. The plants were fertilised with NPK in doses recommended for grasses in field cultivation. In the past two years of research (2011–2012), two swaths of reed canary grass were collected and its yields were determined. Plant samples were dry ashed in a muffle furnace, digested in hydrochloric acid and Ni content was determined by atomic absorption spectrometry with atomisation in the flame (F-AAS). Soil samples were collected in the autumn of 2010 before the foundation of the experiment and determined for the content of nickel by F-AAS, using the 1 mol•dm^{-3}HCl as the extraction solution. The granulometric composition of the soil was determined by areometric-sieve method, pH by potentiometric method in aqueous solution of KCl of 1 mol•dm^{-3} concentration and organic carbon content by Tiurin's method. The contents of phosphorus and potassium in the soil were determined by Egner-Riehm's method, and magnesium by Schachtschabel's method.

The test results concerning the yields of plants were statistically developed using AWAR software program, designed at the Department of Applied Information Technology, the Institute of Soil Science and Plant Cultivation in Pulawy.

3. RESULTS AND DISCUSSION

Plant tolerance to the excess of metals in the soil is determined by an effective control system of its uptake and distribution [Olko 2009]. Studies on physiology and biochemistry of plants show that plants have many defense mechanisms against excessive increases in nickel ion concentration in the tissues. One of the methods to detoxify this metal is its complexation with amino acids and organic acids in the cells of the roots and leaves [Krämer et al. 1996; Yang et al., 1997].

In the first year of vegetation, reed canary grass reacted to the nickel excess in the soil only at the level of contamination 150 mg•kg^{-1} (Ni_2). There was a 50% decrease in the yields of aerial parts of plants compared with Ni_0 treatment (Table 3).

A higher soil contamination with nickel (Ni_3) resulted in extremely negative reactions in plants such as inhibiting the emergence of plants. The research of Korzeniowska, Stanisławska-Glubiak & Igras [2011] showed a reduction in the yields of reed canary grass by several percents at the Ni content of 80 mg•kg^{-1} in the soil.

Application of rock dust into the soil as a remediation material caused the change in the conditions of growth of reed canary grass, depending on the level of soil contamination with nickel. The analysis of the height of the reed canary grass showed a significant interaction between the examined factors. On treatments Ni_0 and Ni, where rock dust had been applied, lower yields were obtained compared with the treatment without the addition of dust, which is difficult to explain. Lower yields on these treatments can result from immobilisation of the elements necessary for the growth and development of plants in the soil. Bolland and Baker [2000] in the field experiments with wheat on the soil uncontaminated with metals obtained a significant reduction in the yields after applying granite dust as a fertiliser (20 t•ha^{-1}). The authors did not find the causes for these low yields.

An increase in the aerial part of reed canary grass due to the addition of rock dust to the soil was obtained only on the Ni_2, where there was an increase in the value of the tolerance index (TI) from 0.55 to 0.77 (Table 4). On Ni_2, despite the addition of dust, the emergences were not observed.

In the second year of vegetation of reed canary grass at the Ni_2 level, the yield of aerial part was still lower than at Ni_0 treatment, and TI increased compared with the previous year from 0.55 to 0.91 (Tables 3 and 4). This indicates a gradual adaptation of plants to nickel stress conditions with time. A consequence of the increase of TI at reed canary grass at the Ni_2 level of contamination was the lack of remediatory effect of rock dust. Generally, no difference was found in plant yields between contaminated and remediation treatments.

A reduction in the yield of reed canary grass in the first year on Ni_2 corresponded to about 40 times higher nickel content in aerial parts in comparison with Ni_0 treatment (Table 5). In the second year, the content of this element on Ni_2 in the aerial part was only about 12 times higher than on Ni_0, while 30 times higher amount was found in the roots.

At the same time, translocation index (TLI) indicates that in the soil with natural Ni content, its accumulation occurred to the same degree in aerial parts and roots, while in nickel-contaminated treatments, it accumulated primarily in the roots.

Application of rock dust resulted in changes in the nickel content in plants, especially on Ni_0 treatment. In comparison with the treatment without dust, two times higher Ni content was observed in aerial parts and about five times in the roots. This was the result of the increased availability of nickel from the soil with the addition of dust, which was confirmed by an increase in the value of bioaccumulation factor (BAF; Table 4). At the same time, on Ni_0 treatment with the addition of dust, there was a radical change in the distribution of nickel in plants, which was mostly accumulated in the roots (Table 5).

On Ni_2 treatment, the application of dust as a remediatory material resulted in lowering the availability of nickel from the soil only

Table 2. Basic physicochemical properties of waste rock dust.

pH (KCl)	d.m.	SiO_2	P_2O_5	K_2O	CaO	MgO	Cr	Zn	Cd	Cu	Ni	Pb	Hg
	g•kg^{-1}						mg•kg^{-1}						
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).

Table 3. The yield of an aerial part of reed canary grass – the sum of swaths (g•m^{-2})

I factor – contamination	2011			2012		
	II factor – remediation					
	Control	Dust	Mean I	Control	Dust	Mean I
Ni_0	689.1	629.3	659.2	728.0	770.2	749.1
Ni_1	776.8	626.6	701.7	716.5	720.0	718.3
Ni_2	380.1	529.6	454.9	664.2	694.2	679.2
Ni_3	Lack of emergences			–	–	–
Mean II	615.3	595.2	x	702.9	728.1	x
LSD I	–			49.96		
LSD II	–			Not significant		
LSD II/I	54.43			Not significant		
LSD I/II	72.98			Not significant		

Table 4. Tolerance of reed canary grass to Ni [TI = biomass of plants (g•m^{-2})/biomass of plants Ni_0 (g•m^{-2})] and the ability to uptake Ni from the soil [BAF = Ni in the plant (mg•kg^{-1})/Ni in soil (mg•kg^{-1})]

Treatment	Tolerance index (TI)				Bioaccumulation factor (BAF)			
	2011		2012		2011		2012	
	Control	Dust	Control	Dust	Control	Dust	Control	Dust
Ni_0	1.00	0.91	1.00	1.06	0.32	0.73	1.33	2.56
Ni_1	1.13	0.91	0.98	0.99	0.31	0.43	0.38	0.40
Ni_2	0.55	0.77	0.91	0.97	0.42	0.36	0.31	0.32
Ni_3	Lack of emergences				–		–	

Table 5. Ni content in the plant (mg•kg^{-1}) and its distribution [TLI = Ni content in aerial parts/Ni content in roots × 100]

I factor – contamination	2011-aerial part		2012-aerial part		2012-roots		Translocation index (TLI)	
	II factor – remediation							
	Control	Dust	Control	Dust	Control	Dust	Control	Dust
Ni_0	1.1	2.1	2.8	6.6	5.4	26.5	51.4	25.0
Ni_1	19.7	29.0	23.4	24.8	114.0	112.0	20.5	22.1
Ni_2	47.6	43.4	32.7	36.0	180.0	152.0	18.1	23.7
Ni_3	Lack of emergences				–		–	

in the first year, which reflected in a slight reduction in BAF and the concentration of this element in the aerial parts. In the second year, there was about 15% decrease in the nickel content in roots as a result of transportation of this element to an aerial part, which reflected in a slight increase in the TLI value.

4. CONCLUSIONS

1. The remediatory efficiency of waste rock dust, applied at a dose of 3 kg•m^{-2} to light soils contaminated with nickel, depended on the content of this element in the soil and was the best at Ni content of 150 mg•kg^{-1}. At a higher level of Ni contamination, the applied dose of dust was not effective.
2. Remediatory effect of rock dust was visible in the first year of plant growth and was based on reducing Ni bioaccumulation. As a result, there was an increase in tolerance of reed canary grass to Ni, which was reflected in the biomass yield.
3. Application of rock dust resulted in changes in the nickel content in plants and its translocation between roots and aerial part.

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