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The response of cucumber (*Cucumis sativus* L.) cultivated in the ion exchanger medium BIONA 312 to nickel

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ABSTRACT

The objective of the studies was to determine sensitivity of cucumber (*Cucumis sativus* L.) 'Hermes' to nickel, as well as the influence of ion exchanger BIONA 312 introduced to the soils contaminated with nickel on its bioavailability. BIONA 312 was introduced in the quantity making 0, 2 or 5% of substrate volume to the substrate contaminated with nickel ($NiSO_4$) in doses: 0, 30, 75 mg Ni dm^{-3}. The susceptibility of cucumber plants to nickel was determined at the florescence and fruiting stage on the grounds of some morphological traits, i.e. root volume, main axis length, number of lateral shoots, leaves, male and female flowers, fruits, as well as nickel content in shoots and roots and cucumber productivity. Nickel at so-called threshold quantities (30 mg dm^{-3}) in the substrate caused significant decrease of female flowers number in florescence stage and severe drop of roots volume in fruiting stage. Also under conditions of higher nickel content (75 mg

dm^{-3}) there was recorded significant decrease of roots volume in fruiting stage. Moreover a complete lack of female and male flowers was observed, which resulted in a lack of fruit crop. Together with substrate contamination with nickel, its content in the cucumber shoots and roots significantly increased. BIONA 312 introduced to the contaminated medium significantly increased the productivity of roots, stems, leaves and fruits, the volume of roots, the main axis length, the number of lateral shoots, leaves, fruits, as well as male and female flowers. Simultaneously, the lower nickel content was recorded in cucumber biomass.

INTRODUCTION

Strong anthropopressure threatens cleanness of the plant nutritive environment, while increase of acid soil area causes the heavy metals mobility growth, including nickel. Therefore the attempts are made to find some effective and economical methods to eliminate or limit metal availability to plants (Raskin et al. 1997, Collins 1999, Chomczyńska et al. 2002). It is very important because heavy metals are very easily introduced to the food chain (Sauerbeck 1989). The effective way to limit the heavy metal bioavailability seems to be the introduction of ionite substrates as a component of soils contaminated with metals.

The objective of this study was to determine sensitivity of cucumber (*Cucumis sativus* L.) to nickel, as well as the influence of ion exchanger BIONA 312 introduced to the soils contaminated with nickel on its bioavailability. From the chemical point of view ionite sorbent BIONA 312 is a mixture of a highly acid cation exchanger KU-2x8 and polyfunctional slightly alkaline anion exchanger EDE-10P saturated with bioelements at appropriate proportions. BIONA 312 contains the following amounts of elements: N - 11.21, P - 3.41, K - 17.60, Ca - 22.24, Mg - 4.38, S - 6.09, Fe - 2.23, Mn - 0.220, Cu - 0.064, Zn - 0.057, Co - 0.015, Mo - 0.044, B - 0.110, Cl - 3.900, Na - 1.380 g kg^{-1}; ion exchanger acidity is pH 6.5-7.0 (Soldatov et al. 1995, Chomczyńska et al. 2002).

MATERIAL AND METHODS

The experiment was conducted in pots of 3 dm^3 capacity in the greenhouse. The control substrate comprised hortisol and quartz sand at rate 2 : 1. The chemical composition of the hortisol was as follows: N - 22.5, P - 0.1, K - 52.4, Ca - 189.7, Mg - 9.2, S - 17.7, Fe - 10.9, Cl - 22.9, Na - 11.8 mg dm^{-3} and 47.8% humus. Regarding the cucumber nutrition requirements, the substrate minerals were supplemented up to: N - 450 (NH_4NO_3 and KNO_3), K - 400 (KNO_3 and KH_2PO_4), Ca - 700 ($CaCO_3$), Mg - 200 ($MgCl_2$), P - 180 (KH_2PO_4) mg per pot. The experiment varied considering nickel content and amount of ion exchanger BIONA 312 introduced to the substrate. Nickel was applied as $NiSO_4$ $7H_2O$ in the following doses: 0, 30, or 75 mg Ni dm^{-3}, while BIONA 312 in the quantity making 0, 2, or 5% of medium volume. The experiment consisted of 9 treatments: two levels of nickel, two levels of ionite substrate and three controls. Five replications in each treatment with two plants in each pot were used and the whole experiment was repeated two times. In the present paper susceptibility of cucumber 'Hermes' to nickel was determined on the grounds of some morphological traits, i.e. root volume, main axis length, number of lateral shoots, leaves, male and female flowers, number of fruits, as well as on the basis of nickel content and cucumber productivity. Root volume was estimated using method described by Sabinin and Kolosov (Basławska and Trubieckowa 1964). The traits mentioned above were determined at the florescence (I) and fruiting stage (II). After dry premineralization of the material nickel content in the cucumber biomass was established with atomic absorption spectrometry method (AAS) on the apparatus Philips PU 9100X model. The least significant difference (LSD) for data concerning the morphological traits, as well as nickel content and cucumber productivity was computed. The significance was declared at $p = 0.05$.

RESULTS AND DISSCUSSION

Cucumber 'Hermes' as compared to the earlier studied 'Wisconsin' (Szymańska and Molas 1994) showed higher tolerance towards nickel presence in the nutritive environment. Nickel content stated in the plants grown at the control conditions (0 mg Ni dm^{-3} – no nickel introduced) proved its presence in hortisol used in the experiment (Table 1). Nevertheless, nickel content at so-called threshold quantities (30 mg dm^{-3}) in the substrate caused very high Ni concentration in the biomass, particularly in roots, still the main axis length, number of leaves and lateral shoots did not show any statistically confirmed changes in comparison to control plants (Tables 1, 2, and 3). At these contamination conditions, however, at both stages (florescence and fruiting) there was detected statistical decrease in the number of female flowers, as well as a significant drop in root volume was recoded at fruiting stage. Higher Ni quantities in the substrate (75 mg dm^{-3}) resulted in a significant growth of its concentration in cucumber biomass. Especially very high increase of Ni content in roots, compared to the shoots, indicate weak translocation of this metal and its retention in the underground parts. Despite such very high concentrations of nickel in the roots and lower, yet still high, in the shoots, no significant changes in the main axis length, number of lateral shoots or leaves were recorded. However, during florescence there was recorded a complete lack of female and male flowers that resulted in a lack of fruit crop (Tables 2 and 3).

Table 1. Nickel content in cucumber biomass (mg kg^{-1} d.m.) depending on the application of BIONA 312 and nickel introduced into the substrate

Dose of BIONA 312 (%)	Dose of Ni (mg dm^{-3})	Shoots	Roots	Mean for BIONA 312 dose		Mean for nickel dose	
				Shoots	Roots	Shoots	Roots
0	0	0.95	4.15	5.33	89.08	1.15	3.74
2		1.65	3.99	4.38	61.91		
5		0.85	3.09	2.61	82.41		
0	30	4.85	66.25			4.20	60.37
2		3.95	50.75				
5		3.80	64.10				
0	75	10.20	196.85			6.98	169.30
2		7.55	131.00				
5		3.18	180.05				
$LSD_{0.05}$ for:		BIONA 312 x Ni		BIONA 312		Ni	
		1.07	11.83	0.50	4.82	0.50	4.82

Moreover, it was noticed that total root volume diminished. The changes brought about by Ni effect on the elongation growth, number of leaves and root volume of cucumber ‘Hermes’ proved to be vital for this plant productivity. That is a result of the Ni biological activity in a plant that inhibits mitoses in the apical meristem and limits the elongation of cell walls formed after the divisions (Baccouch et al. 1998). Yet, a lack of flower buds and flowers manifests plant unreadiness to enter the generative phase. The reasons for plant unreadiness to flower affected by nickel contamination may rise due to the improper calcium homeostasis in cells acting as the secondary messenger in transduction of various signals or some disturbance in the nucleic acid synthesis (Matraszek and Szymańska, in press). The changes of the morphological parameters discussed and productivity resulting from nickel contamination showed a similar character at both observation terms.

Ion exchanger BIONA 312 introduced into the nutritive environment without nickel (0 mg dm^{-3}) in the amounts making 2 or 5% of substrate volume had a significant influence on leaf number and weight, stem weight and main axis length, as well as caused a significant increase in the number of lateral shoots and male flowers per cucumber plant (Tables 2, 3, and 4).

Table 2. Some morphological traits of cucumber plants at the florescence (stage I) depending on the application of BIONA 312 and nickel introduced into the substrate

Dose of BIONA 312 (%)	Dose of Ni (mg dm^{-3})	*1	2	3	4	5	6	7	Mean for BIONA 312 dose 1	2	3	4	5	6	7	Mean for nickel dose 1	2	3	4	5	6	7
0		10.1	21.0	2.0	13.3	0.3	3.0	-	10.0	19.8	2.0	12.1	0.3	1.1	-							
2	0	20.0	57.9	4.7	18.7	1.3	5.0	-	16.4	55.4	4.8	18.1	1.0	4.7	-	18.0	48.3	4.5	17.9	0.9	4.9	-
5		24.0	66.0	6.7	21.7	1.0	6.7	-	23.8	68.1	7.2	22.8	1.2	7.4	-							
0		11.0	21.2	2.0	11.7	0.7	0.3	-														
2	30	16.4	54.2	4.7	17.7	0.3	6.0	-								17.8	46.9	4.5	18.0	0.9	4.4	-
5		26.1	65.4	7.0	24.7	1.7	7.0	-														
0		8.9	17.3	2.0	11.3	0.0	0.0	-														
2	75	12.7	54.0	5.0	18.0	1.0	3.0	-								14.3	48.0	5.0	17.1	0.8	3.9	-
5		21.2	73.0	8.0	22.0	1.3	8.7	-														
$LSD_{0.05}$ for:		BIONA 312 x Ni							BIONA 312							Ni						
		8.5	15.5	1.5	4.4	0.8	1.9	-	3.9	6.8	0.6	1.9	0.3	0.4	-	n.s	n.s	n.s	n.s	n.s	0.4	-

Explanation:
*1 – volume of roots (cm^3) per plant 2 – main axis length (cm) 3 – number of lateral shoots per plant 4 – number of leaves per plant
5 – number of male flowers per plant 6 – number of female flowers per plant 7 – number of fruits per plant

Table 3. Some morphological traits of cucumber plants at the fruiting (stage II) depending on the application of BIONA 312 and nickel introduced into the substrate

Dose of BIONA 312 (%)	Dose of Ni (mg dm^{-3})	*1	2	3	4	5	6	7	Mean for BIONA 312 dose 1	2	3	4	5	6	7	Mean for nickel dose 1	2	3	4	5	6	7
0		30.9	37.0	10.0	15.5	4.5	3.0	1.5	22.6	36.6	9.3	15.3	3.3	2.8	1.2							
2	0	31.7	78.3	15.0	23.5	11.0	3.0	1.5	27.7	79.0	15.0	22.8	10.8	4.3	1.5	35.4	68.4	14.7	21.0	10.5	3.5	1.7
5		43.6	89.8	19.0	24.0	16.0	4.5	2.0	35.3	92.3	18.7	24.8	11.5	5.8	2.5							
0		14.3	34.8	10.0	15.0	2.0	2.5	2.0														
2	30	31.1	80.8	16.5	21.0	12.0	5.0	1.5								28.5	70.0	15.7	20.3	7.8	4.3	2.3
5		40.0	95.0	20.5	25.0	9.5	5.5	3.5														
0		22.7	38.0	8.0	15.5	3.5	3.0	0.0														
2	75	20.3	78.0	13.5	24.0	9.5	5.0	1.5								21.8	69.3	12.7	21.7	7.3	5.2	1.2
5		22.4	92.0	16.5	25.5	9.0	7.5	2.0														
$LSD_{0.05}$ for:		BIONA 312 x Ni							BIONA 312							Ni						
		7.0	2.21	4.8	4.6	6.3	3.2	1.4	3.5	8.7	2.1	1.9	3.1	1.5	0.4	3.5	n.s	n.s	n.s	3.1	1.5	0.4

Explanation: * as in Table 2

Table 4. Cucumber productivity (g d.w. per pot) in two developmental stages depending on the application of BIONA 312 and nickel introduced into the substrate

Dose of BIONA 312 (%)	Dose of Ni (mg dm^{-3})	Leaves	Stems	Fruits	Roots	Mean for BIONA 312 dose: Leaves	Stems	Fruits	Roots	Mean for nickel dose: Leaves	Stems	Fruits	Roots
		Stage I (florescence)											
0		2.90	0.81	-	0.47	2.35	0.75	-	0.46				
2	0	4.87	2.57	-	0.86	4.93	2.44	-	0.75	4.73	2.32	-	0.79
5		6.40	3.57	-	1.02	6.67	3.94	-	1.07				
0		2.33	0.79	-	0.48								
2	30	4.99	2.48	-	0.74					4.78	2.50	-	0.81
5		7.03	4.23	-	1.21								
0		1.81	0.64	-	0.44								
2	75	4.93	2.29	-	0.63					4.45	2.31	-	0.68
5		6.60	4.01	-	0.98								
$LSD_{0.05}$ for:		BIONA 312 x Ni				BIONA 312				Ni			
		1.24	1.12	-	0.67	0.52	0.47	-	0.28	n.s	n.s	-	0.28
		Stage II (fruiting)											
0		3.71	1.59	1.15	1.17	3.50	1.43	0.83	0.91				
2	0	7.35	4.04	1.30	1.32	7.06	4.23	2.62	1.24	6.54	3.91	2.09	1.44
5		8.56	6.09	3.81	1.85	8.32	5.64	5.73	1.71				
0		2.23	1.13	1.34	0.66								
2	30	6.74	4.34	3.31	1.43					6.33	3.69	3.86	1.23
5		8.94	5.61	6.94	1.59								
0		3.47	1.58	0.00	0.91								
2	75	7.09	4.32	3.25	0.98					6.00	3.71	3.23	1.20
5		7.45	5.24	6.45	1.69								
$LSD_{0.05}$ for:		BIONA 312 x Ni				BIONA 312				Ni			
		2.21	1.70	3.97	1.43	0.90	0.69	1.62	0.58	n.s.	n.s.	1.62	n.s

Irrespective of a nickel dose, BIONA 312 (2 or 5%) introduced to the contaminated substrate brought about a significant increase in root volume, the main axis length, number of leaves, lateral shoots, as well as male and female flowers. As a consequence a significant increase in total productivity of leaves, stems and fruits was recorded (Table 4). At these conditions (in particular at 5% BIONA presence) a significant drop of Ni concentration in roots was registered only if this metal quantity in the substrate was high (75 mg Ni dm^{-3}) and in the shoots, whatever the environmental contamination with nickel was (Table 1). BIONA 312 in amount of 5% of substrate volume, irrespective of a contamination level with nickel, showed to be more efficient than 2% dose to reduce phytotoxic impact of this metal. This was clearly noticeable in fruit yield (Tables 2, 3, and 4). A favourable effect of ionite sorbent application in cucumber cultivation on soils contaminated with nickel is likely to result from high absorption capacity of anion exchanger EDE-10P (3.5 mmol g^{-1}), a component of BIONA 312. It decreased nickel mobility and decided about this metal availability to plants. The use of ion exchanger BIONA 312 in the amount of 5% of substrate volume as a constituent of the soils contaminated with nickel for cucumber 'Hermes' cultivation gave positive results. BIONA 312 limited Ni bioavailability that probably resulted from phytostabilization of this metal. In result, better productivity of the vegetative parts, as well as greater yield were observed. In spite of the fact that BIONA 312 application as a component of soils contaminated with nickel was effective, as it reduced availability and prevented the spreading of this metal, it does not solve the problem of plant nutritive environment contamination as it still remains in the substrate.

CONCLUSIONS

1. Ni concentration in the cucumber 'Hermes' biomass, especially in roots, increased together with the increase in substrate contamination with nickel.
2. BIONA 312 introduced to the medium contaminated with nickel significantly decreased Ni content in the cucumber biomass.
3. Nickel content 30 mg dm^{-3} in the substrate caused statistical proved decrease in root volume in the fruiting stage, as well as a significant drop in the number of female flowers in florescence. Under conditions of higher nickel concentration in the substrate a complete lack of female and male flowers was recorded, which resulted in a lack of fruit crop.
4. BIONA 312 introduced to the contaminated medium significantly increased root volume, the main axis length, the number of lateral shoots, leaves, as well as male and female flowers. In consequence, cucumber 'Hermes' productivity was higher.
5. Ion exchanger BIONA 312 in the amount of 5%, as a component in the nickel polluted substrate, gave positive effects in cucumber 'Hermes' productivity.

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REAKCJA OGÓRKA (*CUCUMIS SATIVUS* L.) UPRAWIANEGO W PODŁOŻU Z DODATKIEM SUBSTRATU JONITOWEGO BIONA 312 NA NIKIEL

Streszczenie: W doświadczeniu określano wrażliwość ogórka (*Cucumis sativus* L.) odmiany 'Hermes' na nikiel oraz wpływ substratu jonitowego BIONA 312 na bioprzyswajalność niklu z podłoża. BIONĘ 312 wprowadzano do podłoża z dodatkiem zróżnicowanych dawek niklu ($NiSO_4$), tj. 0, 30, 75 mg Ni dm^{-3}. Dodatek sorbentu jonitowego stanowił 0, 2 lub 5% objętości podłoża zawierającego nikiel. Wrażliwość ogórka na nikiel określano w fazie kwitnienia i owocowania, w oparciu o wybrane cechy morfologiczne, tj. objętość korzeni, długość pędu głównego, liczbę pędów bocznych, liści, kwiatów męskich i żeńskich oraz owoców. Dodatkowo określano zawartość niklu w częściach nadziemnych i korzeniach oraz produkcyjność ogórka. Nikiel w podłożu, w ilościach progowych, tj. 30 mg dm^{-3} wpłynął na statystycznie istotny spadek liczby kwiatów żeńskich w

fazie kwitnienia i znaczne zmniejszenie objętości korzeni w fazie owocowania. Także wyższa dawka niklu (75 mg dm^{-3}) wpłynęła na istotny spadek objętości korzeni w fazie owocowania oraz spowodowała całkowity brak kwiatów żeńskich i męskich w fazie kwitnienia. Wraz ze wzrostem skażenia podłoża niklem istotnie zwiększała się koncentracja tego metalu w korzeniach i pędach ogórka. Dodatek sorbentu jonitowego BIONA 312 do skażonego niklem podłoża wpłynął istotnie na zwiększenie produkcyjności korzeni, pędów, liści, owoców oraz na objętość korzeni, długość pędu głównego, liczbę pędów bocznych, liści jak również na liczbę kwiatów męskich i żeńskich oraz owoców. Równocześnie istotnie zmniejszyła się zawartość niklu w biomasie ogórka.

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