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POST-EFFECT OF INCREASING BOTTOM SEDIMENT ADDITIVES TO THE SUBSTRATUM ON NICKEL UPTAKE BY PLANTS

NASTĘPCZY WPŁYW WZRASTAJĄCYCH DODATKÓW OSADU DENNEGO DO PODŁOŻA NA POBRANIE NIKLU PRZEZ ROŚLINY

Abstract: The aim of the studies was an estimate of post-effect of bottom sediment additives to the substratum on nickel uptake by plants, under conditions of pot experiment. Components of substratum were very acid soil and bottom sediment dredged from Roznow Reservoir. Bottom sediment share ranged from 0 to 16 % of total substratum mass. Test plants were grown in orders: maize (*Zea mays* L.) and faba bean (*Vicia faba* L. var. *minor*), as well as oat (*Avena sativa* L.) and narrowleaf lupine (*Lupinus angustifolius* L.). After vegetation period plants were harvested on green mass. Content of Ni in mineralizats obtained from plant material was determined using ICP-AES method. The total quantity of Ni removed with yield of plants depending on species and part of plant was compared and changes affected by bottom sediment share in substratum as well as previous plant cultivation were estimated.

Under conditions of increased sediment share in substratum significantly higher amounts of nickel were accumulated in roots than in shoots of the plants. On average the highest Ni contents were determined in roots and shoots of faba bean, while the lowest ones in maize roots and shoots. Bottom sediment additions in an amount exceeding 4 % of the substrate mass caused a decrease of Ni content in the aboveground parts of all test plants and sediment additions greater than 10 % reduced these metal content in roots of faba bean and lupine, in comparison with plants from control objects. In case of maize and oat all doses of sediment caused an increase of Ni content in roots. In spite of additional Ni load with applied bottom sediment its increased content in plant tissue of aboveground parts of most test plant was not stated. One may explain this dependence by decreased Ni availability to plants as a result of sediment ability to substratum deacidification.

Considering total Ni uptake the highest its amounts were removed with yield of maize, and the lowest with yield of oat. Significantly higher amount of nickel was taken from the soil in case of maize and faba bean cultivation than in case of variant with oat and lupine. This was due to significantly higher maize biomass yield in comparison with other test plants. The Ni translocation coefficients (TC) (content in shoots *versus* content in roots) as well as bioaccumulation coefficients (BC) (content in shoots *versus* content in soil) for individual plants were calculated. The highest average value of TC was affirmed for faba bean (0.5), lower

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ones for oat (0.29) and lupine (0.21), and the lowest one for maize (0.15). The average values of BC for individual plants decreased as follow: 0.74 – faba bean, 0.37 – oat, 0.31 – lupine, 0.16 – maize.

Keywords: bottom sediment, nickel, plants, uptake, translocation and bioaccumulation coefficient

The formation of sediments in reservoirs over time leads to their silting. There are many ways of their recultivation, however, each of which is associated with the problem of management of dredged sediments from the bottom of the reservoir [1]. Agricultural use of waste materials such as sludge or sediments is the most desirable method of their utilization [2]. Nowadays there are many attempts of agricultural use of materials like bottom sediments, sewage sludge or incineration ashes. These materials are used as so-called indirect fertilizers and may be consider as a source of organic matter and mineral compounds of calcium, phosphorus and nitrogen or materials containing significant amounts of silt and clay fractions [3, 4].

Bottom sediments are rich in mineral elements necessary for proper growth and development of plants. They also have the capacity to soil neutralization, which favors the processes of immobilization of pollutants contained therein. They also show high sorption capacity because of considerable silt and clay content and as a rule large content of organic matter [5]. In case of agricultural use of bottom sediments it is necessary to pay attention at the content of heavy metals in material introduced to the soil, due to the possibility of their entering the human food chain. McBride [6] states that attention should be paid in the absence of basic knowledge about the processes which heavy metals are subject, in each concrete situation of use of waste material for soil amendment. Heavy metals in the environment are not biodegradable, but subjected to processes of biotransformation only [7].

Due to the location of water reservoirs in lower points of the basin, they are becoming receivers of pollutants from upper parts of the catchment area. The chemical composition of sediments of individual reservoirs depends on the type and land use of catchments, as well as on the topography of the terrain [5] According to Polish legislation the bottom sediments from superficial standing or flowing water reservoirs used in earth works are not counted among waste but they should suit standards of soil and earth quality and should fulfill the criteria of admissible values of toxic substances contents, indicated in the enclosure of Minister of Environment regulation [8], for soils occurred in purposed place. Bottom sediment the most often contained elevated amount of trace metals like: zinc, copper, nickel, cadmium, chromium, lead and mercury. Trace elements introduced to the soils may cause an increase of their content in cultivated plants and next enter to human food chain [9]. Many fertilizers used in conventional agriculture contain undesirable substances such as heavy metals, which does not exclude their agricultural use. Bottom sediments dredged from reservoirs contain high amount of calcium carbonate and as a rule magnesium carbonate which may cause the soil neutralization. Deacidification of the substrate during growth of the plants leads to constraint the amount of mobile forms of heavy metals and their availability to plants.

The aim of the study was to estimate the impact of bottom sediment additives to the substratum on nickel uptake by plants and to assess the suitability of this sediment used to soil amendment as material for fertilization and deacidification.

Material and methods

A pot experiment was carried out in 2005 in vegetation hall of University of Agriculture in Krakow. The very acid soil and bottom sediment dredged from Roznow Reservoir were used as components of the substratum (Table 1).

Table 1

The basic properties of components of the substrate

Component	pH		Hh	C_{org}	N_{tot}	P_2O_5	K_2O
	KCl	H_2O				acc. to Egner-Riehm	
			[mmol(+) · kg^{-1}]	[g · kg^{-1}]		[mg · kg^{-1}]	
Sediment	7.20	8.31	—	3.65	1.19	41.3	116
Soil	4.40	5.86	12.2	4.73	0.524	94.3	246

The sediment share in substratum increased as follows: 0, 1, 2, 4, 6, 8, 10, 12, 14 and 16 % of total mass amounting 4 kg d.m. per pot (Table 2).

Table 2

Share of the substratum components and total Ni content in individual experimental objects

Component	Share of substratum component [%]									
Soil	100	99	98	96	94	92	90	88	86	84
Sediment	0	1	2	4	6	8	10	12	14	16
Total Ni content [mg · kg^{-1} d.m.]										
Substratum	5.85	6.25	6.64	7.43	8.22	9.01	9.80	10.59	11.38	12.17

The samples (both roots and shoots) of plants grown at those mixtures were studied material. Test plants were grown in two sequences: maize (*Zea mays* L., 'Prosna F_1' Cv.) and faba bean (*Vicia faba* L., var. *minor*, 'Nadwislanski' cv.) as well as oat (*Avena sativa* L., 'Chwat' cv.) and narrowleaf lupine (*Lupinus angustifolius* L., 'Sonet' cv.). After the vegetation period plants were harvested on green mass, dried and the quantity of shoots and roots biomass was measured. Total content of heavy metals in plant material were determined after dry mineralization and dissolving in hot nitric acid, while in samples of substratum after dry mineralization of organic matter and digestion in a hot mixture of concentrated acids: HNO_3 and $HClO_4$ (3:2; v/v). Heavy metals concentrations in obtained solutions were assayed by ICP-AES method.

Results and discussion

Soil and bottom sediment used in experiment contained relativity high amount of Ni: 5.85 mg · kg^{-1} and 45.33 mg · kg^{-1} of d.m., respectively [10].

With increasing share of bottom sediment in substratum total nickel content increased as well (Table 2). In spite of additional Ni load, with applied small additions of bottom sediment (1–4 %), nickel content in all of the test plants shoots as well as faba bean and lupine roots stayed at higher but similar level in comparison with plants of control objects. A decrease of Ni content in mentioned parts of test plants was found when share of sediment in substratum raised to 10 %. Different response was observed in case of oat and maize roots which accumulated enhanced quantities of Ni almost parallel to its increasing up content in substratum. The higher than 10 % additions of bottom sediment to the substratum caused decrease of Ni content in shoots and roots of all test plants (Fig. 1). On average the highest amount of Ni was found in shoots and roots of faba bean and the lowest ones in both these parts of maize.

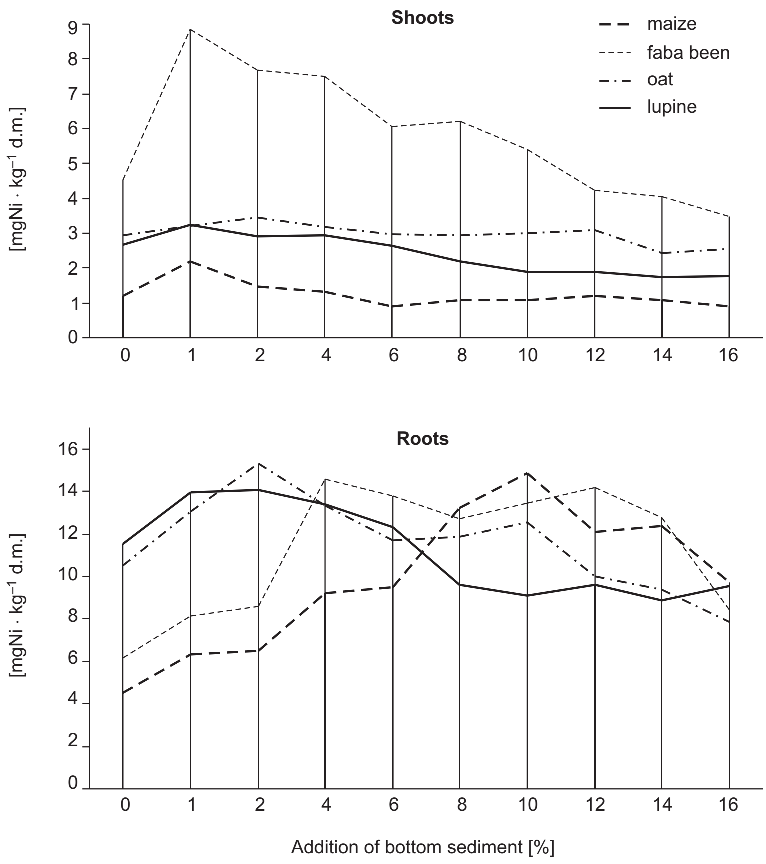

Fig. 1. Ni contents in shoots and roots of test plats depend on share of the bottom sediment in substratum

Heavy metals absorption by plants from substratum depends on many factors [11]. In general, under conditions of soils contaminated with trace elements, it is substantial to reduce their availability to plant, using different methods. Limitation of heavy metals availability, absorption and their entering human food chain should be an effect of these efforts. Ni quantities removed with yield of test plant roots were significantly higher than of aboveground biomass (Fig. 2).

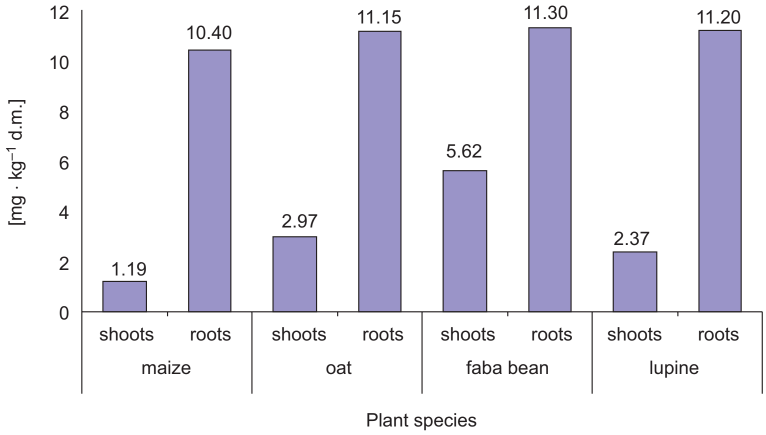

Fig. 2. The average Ni contents in plant tissues of individual species

Considerably great quantities of Ni were accumulated in roots, because nickel absorption by these parts of plant is mainly a passive process and almost proportional to amount of its soluble forms occurring in substratum [9]. The amount of nickel removed by maize increased with successive additions of bottom sediment, and the highest uptake for this plant was stated at a 10 % share of bottom sediment in the substrate. In case of other test plants increasing share of bottom sediment did not affected significant changes of nickel uptake from the substrate (Fig. 3).

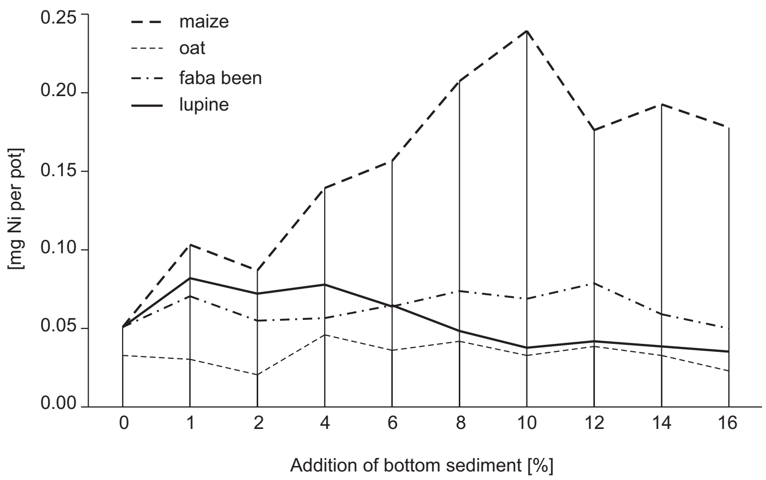

Fig. 3. Amount of Ni removed with yield of test plants depend on sediment addition to the substratum

On average, the most quantities of Ni were removed with yield of maize, what was associated with significantly higher biomass production by this plant, in comparison with the other tests plants, cultivated in presented experiment (Fig. 4). On average, significantly higher amounts of nickel was uptake in plant succession: maize and faba bean (0.221 mg per pot) than with yield of second one – oat and lupine (0.083 mg per pot). This was due to significantly higher amount of total biomass yield of maize and faba bean in this pot experiment.

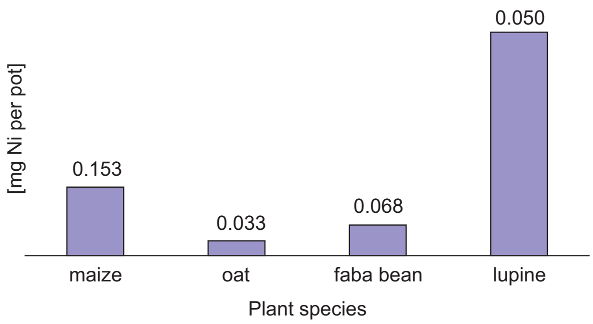

Fig. 4. The average total amount of Ni removed with yield of test plants

Bioaccumulation coefficient (BC) expresses relation between element content in plant and its content in soil. In general, with increasing share of bottom sediment in the substratum the values of Ni bioaccumulation coefficient calculated for individual test plants decreased (Fig. 5).

Analysis of calculated values of Ni BC showed that on average the highest amounts of this metal was accumulated in aboveground parts of faba bean, while the lowest ones

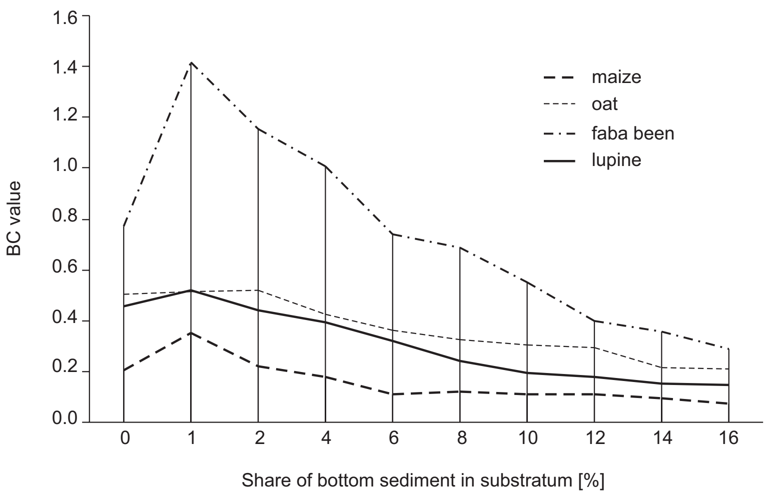

Fig. 5. The value of BC of Ni for shoots of test plants depending on bottom sediment share in substratum

in shoots of maize. Significantly higher values of BC were noted in case of faba bean comparison with the other plants (Fig. 5). In accordance with the data of other authors [12] dicotyledonous plants accumulated more Ni than monocotyledonous ones, independently on contamination level of substratum.

On average, the lowest values of BC were stated in case of plants, which accumulated the smallest amounts of Ni in their aboveground parts (Fig. 6). The lowest average content of this element were affirmed for shoots and roots of maize. The highest average content of Ni was found in aboveground parts of lupine and in roots of faba bean.

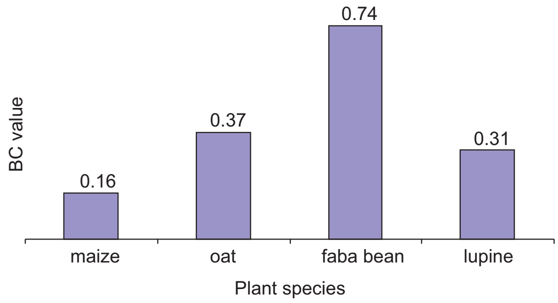

Fig. 6. The average *bioaccumulation coefficient* values (BC) for Ni in plants shoots

The translocation coefficient (TC) is a ratio of trace element content in shoots *versus* its content in roots. It informs about scale of substances movement from roots to above-grounds parts of plant. There are many plants defense mechanisms, generated by plants cultivated under conditions of contaminated substratum. One of them is reduction or prevention of toxic substances transport to vegetative and generative parts [13]. This relationship is confirmed by the low values of Ni translocation coefficient calculated for tests plants (Fig. 7).

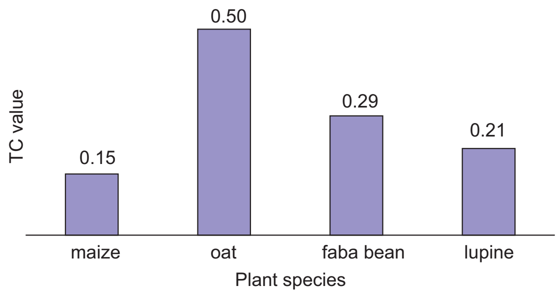

Fig. 7. The average *translocations coefficient* (TC) values calculated for individual plant

The values of translocation coefficients for all test plants did not exceed 0.7 and were considerable lower than observed in case of wild plants species belonging to different biological families which ranged from 1 to 4.4 [14]. The highest average translocation coefficient value was stated in case of faba bean (0.5), lower one for oat (0.29) and lupine (0.21) while the lowest value of TC was noted for maize (0.15).

With increasing share of bottom sediment in substratum decreased the values of translocation coefficient (Fig. 8). One may explain this dependence by decreasing Ni solubility after application of sediment, because of its ability to substratum neutralization. Increase of substratum pH value during plants growth period caused decrease of nickel availability to plants and in consequence decrease Ni content in roots, what resulted in relative increase of translocation coefficient value [15]. Bottom sediment dredged from Roznow Reservoir affected the properties of substratum similarly like liming and caused an increase of pH value up to neutral one. According to Sapek [16] liming is one of the paramount factors which reduce heavy metals mobility, therein Ni, in soil – plant system.

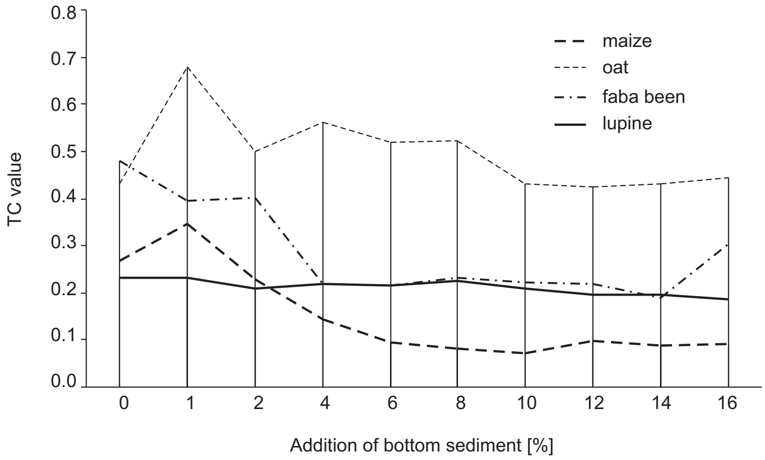

Fig. 8. The value of Ni translocation coefficient (TC) in tested plants dependent on share of bottom sediment in substratum

Conclusions

1. Under conditions of increased share of sediment in substratum significantly higher amounts of Ni were accumulated in roots than in shoots of the plants.

2. Bottom sediment additions in an amount exceeding 4 % of the substratum mass caused a decrease of Ni content in aboveground parts of all test plants and roots of faba bean and lupine. Sediment additions greater than 10 % reduced nickel content in all these parts of test plant below its level in plants of control objects.

3. All sediment additions cause an increase of Ni content in roots of maize and oat, and its share in substratum higher than 10 % decrease nickel content in roots of these plants but Ni level was still higher than in plants of control objects.

4. On average, the highest Ni contents were determined in lupine roots and faba bean shoots, while the lowest ones in maize roots and shoots.

5. The highest total quantities of Ni were removed with yield of maize, and the lowest one with yield of oat.

6. In a spite of additional nickel load with bottom sediment applied in experiment an increase of Ni accumulation in plants was not observed because of sediment ability to substratum neutralization and increase of sorption capacity.

7. With increasing share of bottom sediments in substrate decrease of value of BC in case of all tests plants was noted.

8. Rise of bottom sediment share in substrate caused a decrease of TC in case of all plants in comparison with control objects as a result of limitation of Ni content in roots.

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NASTĘPCZY WPŁYW WZRASTAJĄCYCH DODATKÓW OSADU DENNEGO DO PODŁOŻA NA POBRANIE NIKLU PRZEZ ROŚLINY

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Abstrakt: Celem badań była ocena następczego wpływu dodatku osadu dennego do podłoża na pobranie niklu przez rośliny w warunkach doświadczenia wazonowego. Jako komponenty podłoża użyto glebę lekką, bardzo kwaśną oraz osad denny bagrowany ze Zbiornika Rożnowskiego. Udział osadu dennego wynosił od 0 do 16 % całkowitej masy podłoża. Rośliny uprawiano w kolejności: kukurydza (*Zea mays* L.) i bobik (*Vicia* *faba* L. var. *minor*) oraz owies (*Avena sativa* L.) i łubinu (*Lupinus angustifolius* L.). Po okresie wegetacji rośliny zebrano na zieloną masę. Zawartość Ni w mineralizatach uzyskanych z materiału roślinnego oznaczono metodą ICP-AES. W pracy porównano całkowitą ilości Ni odprowadzoną z plonem roślin testowych w zależności od gatunku i części rośliny oraz oszacowano zmiany powodowane dodatkiem osadu dennego do podłoża, a także następstwem roślin po sobie.

W warunkach zwiększającego się udziału osadu w podłożu znacznie większe ilości niklu zostały zgromadzone w korzeniach niż w łodygach roślin. Średnio najwięcej Ni zawierały korzenie łubinu i bobiku, a najmniej korzenie i łodygi kukurydzy. Dodatki osadu dennego w ilości przekraczającej 4 % masy podłoża powodowały zmniejszenie zawartości Ni w częściach nadziemnych wszystkich roślin testowych, a dodatki osadu większe niż 10 % zmniejszyły zawartość tego metalu w korzeniach łubinu i bobiku, w porównaniu z obiektami kontrolnymi. W przypadku kukurydzy i owsa wszystkie dawki osadu powodowały wzrost zawartości Ni w korzeniach. Pomimo zwiększonego ładunku Ni w podłożu wprowadzonego z zastosowanym osadem dennym nie następował wzrost zawartości tego metalu w częściach nadziemnych większości roślin testowych. Taką zależność można tłumaczyć ograniczeniem dostępności Ni dla roślin na skutek odkwaszającego działania osadu dennego do podłoża.

Biorąc pod uwagę całkowite pobranie Ni, najwięcej tego metalu zostały odprowadzone z plonem kukurydzy, a najmniejsze z plonem owsa. Znacznie więcej niklu pobrały z gleby rośliny uprawiane w następstwie kukurydza–bobik niż w następstwie owies–łubin. Było to spowodowane znacznie większym plonem biomasy kukurydzy w porównaniu z pozostałymi roślinami testowymi, co przełożyło się na znacznie większe pobranie niklu z podłoża. Obliczono *współczynniki translokacji* Ni (WT) (zawartość w częściach nadziemnych *versus* zawartość w korzeniach) oraz *współczynnik bioakumulacji* (WB) (zawartość w częściach nadziemnych *versus* zawartość w glebie) dla poszczególnych roślin. Najwyższą średnią wartość WT stwierdzono dla bobiku (0,5), niższą dla owsa (0,29) i łubinu (0,21), a najniższą dla kukurydzy (0,15). Średnie wartości WB dla poszczególnych roślin malały następująco: 0,74 – bobik, 0,37 – owies, 0,31 – łubin, 0,16 – kukurydza.

Słowa kluczowe: osad denny, nikiel, rośliny, pobranie, współczynnik translokacji, współczynnik bioakumulacji