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ORIGINAL PAPER

PHYTOEXTRACTION OF COPPER AND NICKEL FROM SOILS CHARACTERIZED BY DIFFERENT DEGREES OF CHLORIDE SALINITY

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Abstract

Phytoremediation is a relatively modern technology that uses higher plants for the cleanup of polluted habitats. An example of this technology is phytoextraction, which uses metal-accumulating plants to remove toxic elements from contaminated soil. The effect of phytoextraction depends mostly upon the selection of a proper plant species, able to accumulate the desired element in specific environmental conditions. This is especially important in the case of saline soils. The aim of the present study was to determine the opportunity of using two plant genera (*Zea mays* L., *Heliantus annus* L.) to extract copper and nickel from the soils of different salinity. For this purpose, an investigation into the plants' growth and development traits, as well as a determination of the quantitative distribution of Ni and Cu in the parts of corn were carried out. It was established that the ability of plants to extract metals depended on the salt content in soil. At moderate soil salinity (0.3% NaCl), it increased up to 13% for copper and 20% for nickel in comparison with non-saline soil. Metal concentrations in tissues of *Zea mays* after 14-day cultivation in saline (0.3% NaCl) and non-saline soils with different concentrations of metals (50-2000 mg kg^{-1}) were studied. The increasing NaCl concentration promoted a higher rate of metal transfer from roots to aerial parts and metal phytoextraction process. At the co-occurrence of the metals in soil, copper was more preferable by *Zea mays* than nickel. It was proven in the field experiments that during the whole growing period of *Zea mays* most of the metals accumulated in roots and stems, but not in ears, which allows us to use corn ears for food purposes.

Keywords: phytoextraction, soil, nickel, copper, chloride salinity, corn, sunflower.

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INTRODUCTION

The preservation and rational use of the crucial natural resource of the Earth, such as fertile soil, are among the most important environmental problems. Soil degradation, which appears as a consequence of natural phenomena or inappropriate land use practices, is a significant threat to food security of the planet. The increasing human impact leads to essential changes in soil, such as salinity and contamination by toxic non-degradable substances, loss of organic matter and biodiversity, as well as desertification processes (Ibraeva et al. 2010, Gardi et al. 2013).

Ever since the onset of the Technological Revolution, the progress in different branches of industry and transportation has contributed to a huge consumption of energy. This has seriously influenced different habitats, significantly increasing the contamination with organic and inorganic substances. Heavy metals are among inorganic pollutants of soils that have been the most intensively investigated and frequently found (Galiulin et al. 2002, Wiłkomirski et al. 2012).

Environmental pollution, including atmospheric contamination, involves aerosol migration followed by precipitation onto the ground surface. Such contamination can migrate to the subsoil, surface and ground water. The most common heavy metals from airborne sources, including copper and nickel, are important since they not only decrease crop production but also create a risk of bioaccumulation and biomagnification in the food chain (Wuana, Okieimen 2011). Finally, the accumulation in human organisms promotes development of various pathological syndromes (Khan et al. 2008, Jaishankar et al. 2014). Thus, remediation of soils contaminated with heavy metals is a current task in the environmental sciences.

Soil salinity affecting large areas is another global problem, especially because of the harmful effects on plant growth and crop yields. In some regions of Russia, active land irrigation leads to increasing the soil content with heavy metals (Pankova 2015). Such situation occurs for example in the Volga-Caspian region of Russia, particularly on the left bank of the Volga River near Saratov. The fundamental cause of this phenomenon is the industrial emission. An analysis of harmful elements in the soil of this region showed an increased content of lead, molybdenum, zinc, copper and nickel. Especially the two latter metals cause serious environmental problems in the investigated areas. As usual, their content in agricultural lands is 2.5-fold higher than the maximum permissible concentration (MPC). The greatest soil pollution with copper and nickel is determined near the city, where it is about 20-30 times higher than the MPC.

Most agricultural lands in the region are arable and the soils belong to good quality type. About 75% of them are occupied by chernozems and 13% by dark-chestnut ground. For this reason, the contribution of agriculture to the region's economy should be significant. However, contamination and salinization decrease the effect of soil fertility. Moderate saline soils of chloride type are common in this region (Shuravlin, Kasyanov 1988). The problem of desertification of soils in this region is also observed (Prudnikova, Savin 2015).

Various techniques can be used for reduction of the metal and salt content in soil (Rabhi et al. 2009). Generally, all methods applied for the sake of soil decontamination can be divided in two groups, depending on the place of action, i. e. *in-situ* or *ex-situ* (Pavel, Gavrilescu 2008). The main advantage of *ex-situ* methods is that they generally require shorter time periods than *in-situ* techniques, although an *ex-situ* approach requires excavation of soils, which is usually expensive and complicated.

The method of phytoextraction, which exploits plant-soil interactions, is one of the most popular *in-situ* techniques. Heavy metals may be extracted from soil by the plant root system and concentrated in the harvested biomass, which can be further removed and treated in different ways (Roundhill 2004, Pilon-Smits 2005). Specific plant species are able to absorb and accumulate or even hyperaccumulate metal contaminants (Tangahu et al. 2011).

Copper (Cu) and nickel (Ni) are widespread in the environment, due to both anthropogenic and natural sources. Many species of plants have been successful in absorbing Cu and Ni, hence phytoextraction can be used to remove these elements from soil. The group of plants with a relatively high biological accumulation ability for Cu and Ni is known to include lettuce, salvinia, sorrel, fescue and some others (Galiulin et al. 2002, Das, Goswami 2016) Unfortunately, most of the above Cu/Ni accumulating plants are identified as slow growing and small organisms, which produce low biomass and have indeterminate growth requirements and characteristics.

In the present study, two plant species of agricultural significance, i.e. common sunflower (*Heliantus annus* L.) and corn (*Zea mays* L.), were used. An important reason why there were chosen was that they are typical plant crops for the Saratov region. Moreover, they produce high biomass, possess economic value and have been known as metal-accumulating plants (Rashid et al. 2008, Wilhelm et al. 2009).

The main objectives of the present study were:

(1) to investigate the influence of copper and nickel concentration in the soils of various salinity on the growth and development of sunflower and corn;

(2) to determine the ability of sunflower and corn to accumulate metals (Cu, Ni) depending on the salinity of the soil;

(3) to determine quantitative distribution of Ni and Cu in different parts of corn;

(4) to investigate extraction process of Ni^{2+} and Cu^{2+} ions occurring simultaneously in nonsaline and moderate saline soils;

(5) to control phytoextraction process at the end of the first growing season of corn.

MATERIAL AND METHODS

Corn (*Zea mays* L.) and common sunflower (*Heliantus annus* L.) were used in laboratory and field investigations. In the laboratory experiments, floral natural soil ("Saint-Petersburg Turfy Company" ТУ 3842-113--54896325-2002) was used.

In the laboratory experiments, soil was preliminary dried up to the air-dry state at a temperature of +40°C. Samples of dry soil (50 g) were placed in 200 ml plastic cups.

Water solutions of $NiSO_4 \cdot 7H_2O$, and $CuSO_4 \cdot 5H_2O$ were added into soil samples to simulate the specified degree of copper or nickel contamination, taking into account that MPC_{Ni} = 100 mg kg^{-1} of soil, MPC_{Cu} = 55 mg kg^{-1} of soil (Tables 1, 2).

Water solutions of sodium chloride were added into soil samples in order to obtain NaCl concentrations of 1.5; 3; 6; 12; 24; 48 g kg^{-1} of dry soil. Thus, we simulated different degrees of soil salinity (Shuravlin, Kasyanov 1988, Shahid et al. 2013). Gradation of the total soil salinity was chosen according to the Russian saline soil classification (Shuravlin , Kasyanov 1988): non saline soils (less than 0.15%), light saline (0.15-0.3%), moderate saline (0.3-0.6%), strong saline (up to 1.0%) and solonchacks (more than 1.0%). This classification is similar to that adopted in China and Vietnam (Shahid et al. 2013).

Table 1

Recalculation of nickel sulphate concentration

C ($NiSO_4 \cdot 7H_2O$) (g kg^{-1} of soil)	C (Ni^{2+}) (g kg^{-1} of soil)	Multiple value of MPC_{Ni}
0.5	100.0	1.0
1.2	250.0	2.5
2.4	500.0	5.0
4.8	1000.0	10.0
9.5	2000.0	20.0

Table 2

Recalculation of copper sulphate concentration

C (Cu $SO_4 \cdot 5H_2O$) (g kg^{-1} of soil)	C (Cu $^{2+}$) (g kg^{-1} of soil)	Multiple value of MPC_{Cu}
0.2	50.0	10
0.4	100.0	2.0
1.0	250.0	5.0
2.0	500.0	10.0
4.0	1000.0	20.0

Ten seeds of the investigated plant were placed in each soil sample and were cultivated in laboratory under natural light for 14 days in May at a temperature of 22-25°C. The length and weight of roots and shoots were measured after removing plants from soil, washing and air drying. Each experiment was performed tree times.

Field experiments were carried out as follows: 18 bottomless wooden boxes (50×50 cm) were placed in soil to the depth 30 cm and filled with air-dry soil; water solution of sodium chloride was added into 9 boxes, creating 0.3% NaCl that corresponds to moderate saline soil. Water solutions of $CuSO_4 \cdot 5H_2O$ and $NiSO_4 \cdot 7H_2O$ were added into boxes to achieve appropriate ratios of the Cu^{2+}:Ni^{2+} concentrations (mg kg^{-1} of soil): 50:100, 50:250, 50:500, 100:100, 100:250, 100:500, 250:100, 250:250, 250:500. 10 seeds of corn were sown in each box. Corn was growing during the summer period, since May until August. The plants were regularly watered. After maturing, corn ears were cut and roots were extracted from soil. Roots, leaves, stems and ears were prepared for determination of the Ni and Cu content in biomass.

The content/concentration of metals in soil and air-dried biomass samples was tested using an X-ray fluorescent spectrometer SPECTROSCAN MAX G2E. All measurements were repeated three times.

Mathematical processing of the experimental data was carried out using computer program Microsoft Excel 2007, where the arithmetic mean for each experiment, confidence interval and average standard deviation were calculated. The reliability of the results was estimated at $p = 0.95$.

RESULTS AND DISCUSSION

Soil is a very special component of the natural and agricultural terrestrial ecosystems owing to its role in the growth of plants as well as in the degradation and recycling of dead biomass. The basic physical, chemical and biological properties of soils must be considered to maintain sustainable agricultural practices (Parikh, James 2012). In turn, sustainable development of rural areas is one of the main factors to ensure not only food security but also social integrity of the region. Two factors causing soil degradation, i.e. soil salinity and soil contamination with heavy metals, are obviously severe environmental hazard (Metternicht Zinck 2003, Chibuike, Obiora 2014). Hence, any investigation dealing with the remediation of saline and contaminated soil is helpful in making correct decisions regarding management practices.

Agronomic plants with high annual biomass, including *Helianthus annuus* and *Zea mays,* have been formerly used for phytoextraction of heavy metals from surface soils (Meers 2005, Kacalkova et al. 2014). However, there is lack of complex reports dealing with phytoextration by sunflower and corn from soil that is not only contaminated but also saline one.

The study of common sunflower and corn growth and development in soils NaCl-salted and contaminated with copper and nickel

The seeds of sunflower and corn were cultivated in soil characterized by various NaCl-salinity degrees (0.15; 0.3; 0.6; 1.2; 2.4; 4.8%) and different concentrations of Cu^{2+} (50-1000 mg kg^{-1}) and Ni^{2+} (100-2000 mg kg^{-1}). The growth and development of corn and sunflower were observed for two weeks. Afterwards, the plants were harvested and the biometric parameters of shoots were measured (Tables 3-5).

The data presented in Table 3 indicate that the toxicity of NaCl towards the investigated species is evidently visible at the concentration 0.3% (moderate saline soil). In soil with 0.6% NaCl, corn and sunflower germination decreased by 50 and 40%, respectively, whereas the length and mass of shoots of the both plants decreased 2- to 3-fold compared to the control. The further increase of NaCl concentration led to an even more significant inhibition of the plant growth. However, both plants showed the ability to grow in moderate salinity soils.

The data presented in Tables 4 and 5 show that the investigated plants are quite stable under relatively high concentrations of copper and nickel in soils. Increasing the metal concentration up to the values equal to 20 MPC

Table 3

Effect of NaCl-salinity degree of soil on the parameters of plant growth and development

NaCl concentration, (% of dry soil mass)	Plant parameters		
	germination (%)	length of shoots (mm)	mass of shoots (mg)
Zea mays L.			
Control	100.0	151.0 ± 10.2	394.8 ± 11.9
0.15	90.0	134.5 ± 9.9	329.1 ± 9.3
0.30	70.0	109.5 ± 9.2	245.6 ± 12.1
0.60	50.0	53.0 ± 8.5	183.5 ± 7.4
1.20	30.0	10.0 ± 5.3	94.0 ± 6.7
2.40	10.0	8.0 ± 5.0	32.8 ± 4.8
4.80	0.0	---	---
Heliantus annus L.			
Control	100.0	125.5 ± 10.9	204.0 ± 15.4
0.15	100.0	118.5 ± 11.2	195.6 ± 12.40
0.30	90.0	88.0 ± 10.1	142.3 ± 6.7
0.60	60.0	67.0 ± 4.3	99.5 ± 5.9
1.20	30.0	30.5 ± 4.9	32.8 ± 3.9
2.40	20.0	11.5 ± 3.1	19.1 ± 5.4
4.80	0.0	---	---

Table 4

Effect of Cu^{2+} contamination of soil at the parameters of plant growth

Concentration of Cu^{2+} (mg $kg^{-1}$of dry soil)	Plant parameters		
	germination (%)	length of shoots (mm)	mass of shoots (mg)
Zea mays L.			
Control	100.0	151.0 ± 10.2	394.8 ± 11.9
50.0	100.0	163.0 ± 11.3	426.7 ± 14.3
100.0	100.0	148.0 ± 11.0	356.9 ± 12.0
250.0	90.0	96.0 ± 9.9	219.0 ± 9.3
500.0	80.0	84.0 ± 7.3	174.6 ± 9.1
1000.0	60.0	61.0 ± 6.8	145.4 ± 7.5
Heliantus annus L.			
Control	100.0	125.5 ± 10.9	204.0 ± 15.4
50.0	100.0	129.0 ± 11.8	210.8 ± 16.6
100.0	90.0	121.0 ± 10.1	165.8 ± 10.5
250.0	80.0	89.5 ± 9.2	119.3 ± 9.1
500.0	60.0	63.5 ± 9.5	107.3 ± 5.7
1000.0	40.0	49.0 ± 5.5	99.5 ± 6.0

reduced the corn germination only to 60–40%, and sunflower germination to 50-30%, while causing a 2- to 3-fold decrease in the length and mass of shoots. Therefore, the investigated plant species may be used for further studies on their metal extraction activity.

The study of common sunflower and corn ability to extract ions of nickel and copper from soil with different salinity degrees

The seeds of sunflower and corn were cultivated in soil samples without NaCl (modelling non-saline soil), with 0.3% NaCl (modelling moderate saline soil) and 0.6% NaCl (strong saline soil), containing various concentrations of Cu^{2+} (50-1000 mg kg^{-1}) and Ni^{2+} (100-2000 mg kg^{-1}). The growth and development of corn and sunflower were observed during 14 days.

In moderate saline soil, even at the maximum content of copper ions (20 MPC), 90% germination of seeds was observed. In strong saline soil, at a copper concentration equal to 10 MPC, the number of corn and sunflower shoots decreased to 45 and 50%, respectively. In moderate saline soil contaminated with nickel – regardless of its concentration – the maximum germination of seeds was observed. In non-saline and strong saline soil, the percentage of shoots decreased proportionally to the increase in the metal concentration. Thus, it was established that that maximum resistance of corn and sunflower to nickel and copper contamination takes place in moderate saline soil.

Table 5

Effect of Ni^{2+}contamination of soil at the parameters of plant growth

Concentration of Ni^{2+} (mg kg^{-1} of dry soil)	Plant parameters		
	germination (%)	length of shoots (mm)	mass of shoots (mg)
Zea mays L.			
Control	100.0	151.0 ± 10.2	394.8 ± 11.9
100.0	90.0	152.0 ± 10.2	367.0 ± 12.0
250.0	80.0	122.3 ± 7.9	328.5 ± 10.4
500.0	80.0	113.0 ± 9.3	272.5 ± 14.0
1000.0	60.0	93.0 ± 8.1	224.0 ± 9.6
2000.0	40.0	63.5 ± 6.3	156.7 ± 10.7
Heliantus annus L.			
Control	100.0	125.5 ± 10.9	204.0 ± 15.4
100.0	100.0	125.0 ± 12.8	200.0 ± 10.3
250.0	80.0	99.5 ± 9.0	177.9 ± 12.6
500.0	70.0	76.0 ± 9.1	139.0 ± 10.7
1000.0	50.0	60.5 ± 7.2	118.4 ± 8.8
2000.0	30.0	40.0 ± 5.1	94.2 ± 7.9

After the plants were removed from the soil, the Cu and Ni content was measured in it. The ability of plants to extract metals was evaluated by the reduction in the concentration of the metals in the soil. In Figures 1 and 2, the dependency of the percentage of metal mitigation in soils after plant cultivation (equal to the quantity of the extracted metal) in relation to the initial concentration of metals in soil and its salinity degree are presented. The initial concentration of Ni^{2+} and Cu^{2+} (X-axis) is presented in values multiple to the MPC of these metals in soils.

Figures 1 and 2 show that the ability of plants to extract nickel and copper decreases with the increasing metal content in the soil, and also depends on its salinity degree. Both plants were unable to extract metal ions from the soil containing 0.6% NaCl and contaminated with nickel or copper in a quantity 20-fold higher than their MPC. In moderate saline soil (0.3% NaCl) with the same content of the metals, the investigated plants extracted 25-30% of the quantities of the metals. We noted significant differences (p = 0.95) in the quantity of extracted metals from the soil containing 0.3% and 0.6% NaCl. In the case of soil salinity (0.3% NaCl) and contamination with copper at the level of 2.5-5 MPC and nickel at the level of 2.5-20 MPC, the ability of the plants to extract the metal ions significantly increased by nearly 13% and 10-20%, respectively, in comparison to non-saline soil.

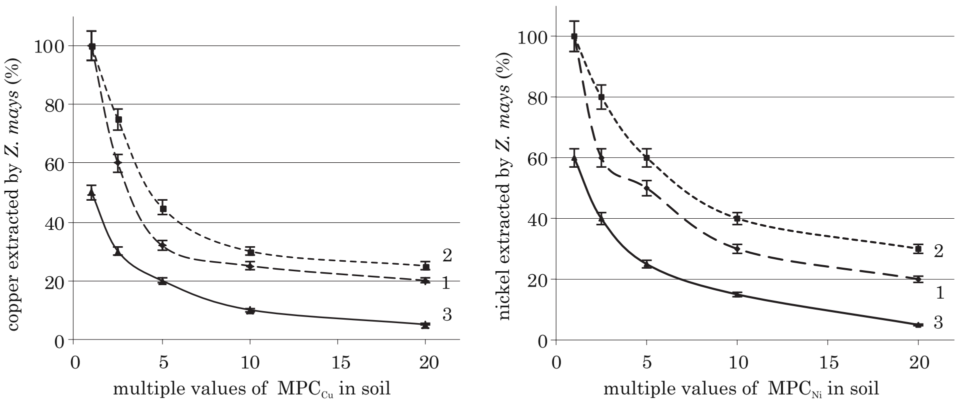

Fig. 1. Dependences of extracted quantity of copper and nickel by *Z. mays* (%) in relation to their initial concentration in soil characterized by different salinity degrees: 1 – non-saline soil, 2 – saline 0.3% NaCl, 3 – saline soil 0.6% NaCl

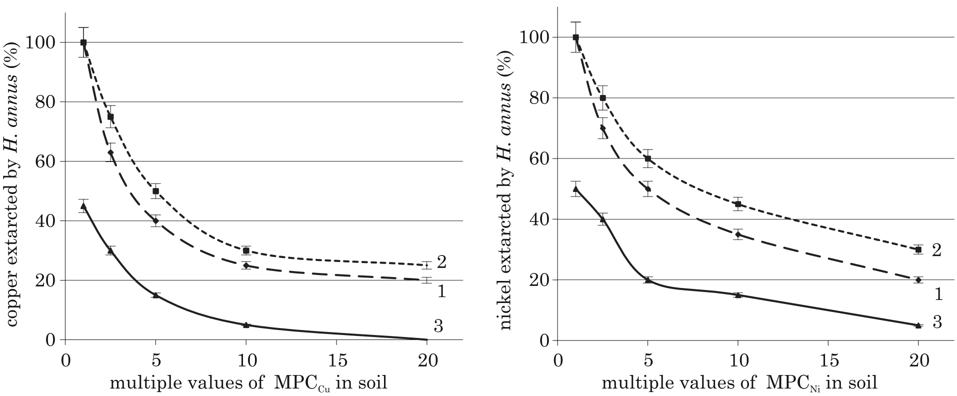

Fig. 2. Dependences of extracted quantity of copper and nickel by *H. annus* (%) in relation to their initial concentration in soil characterized by different salinity degrees: 1 – non-saline soil, 2 – saline 0.3% NaCl, 3 – saline soil 0.6% NaCl

The study of quantitative distribution of Ni and Cu in the plant parts of corn

Corn was cultivated in soil with 0.3% NaCl contaminated with Cu^{2+} (50-1000 mg kg^{-1} of soil) and Ni^{2+} (100–2000 mg kg^{-1} of soil) for 2 weeks. Next, the plants were harvested and the content of Cu and Ni was measured in dry biomass of roots and shoots. The results of the experiments concerning the distribution of these metals in different parts of corn are presented in Figure 3.

At the first stages of the plant growth (14 days), most of metals (Figure 3) accumulated in roots of corn, which is on accord with the literature data for other heavy metals (Seregin, Ivanov 2001, Xu et al. 2013). At an initial concentration in soil of Cu^{2+} 100 mg kg^{-1} and Ni^{2+} 500 mg kg^{-1}, soil salinity pro-

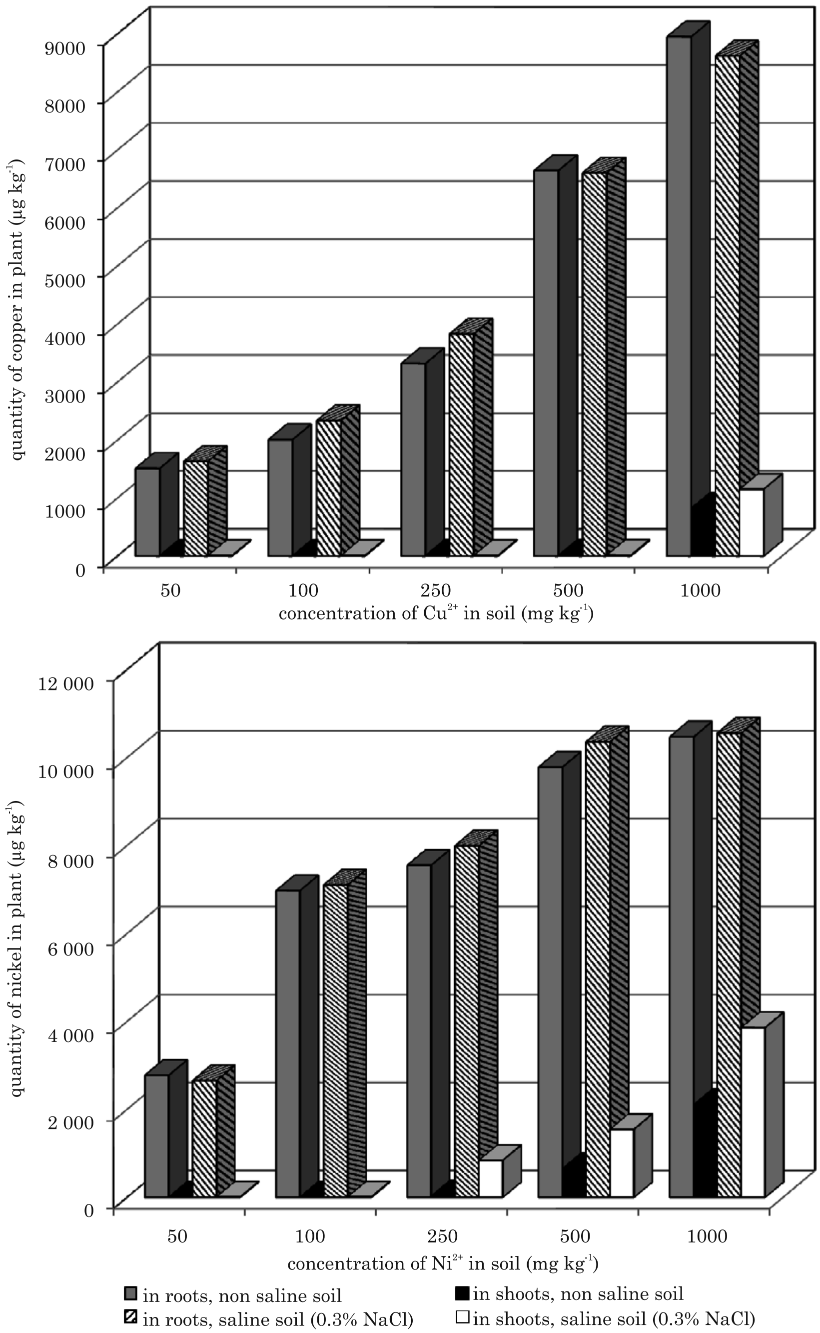

Fig. 3. Dependence of copper and nickel content (μg kg^{-1} of dry biomass) in roots and shoots of corn, cultivated for 14 days in laboratory conditions, on the initial concentration of metals in saline (0.3% NaCl) and non-saline soils

motes the process of phytoextraction and metal transition from roots to shoots. Probably, the metal content increases in shoots only after the roots' absorbing ability reaches its limit (NETTY et al. 2013). We hypothesize that moderate salinity of soil promotes more active transportation of metal ions from roots to stems and leaves. It was noted that phytoextraction of nickel in non-saline and moderate saline soil occurs more effectively than that of copper. The ability of corn to extract nickel and copper ions increased with an increasing concentration of these metals in soil.

The study of phytoextraction process of Ni^{2+} and Cu^{2+} ions at their mutual presence in non-saline and moderate saline soil by corn in a field experiment

The model experiments allowed us to conclude that corn can successfully extract Ni^{2+} and Cu^{2+} ions at their mutual presence in soil in a concentration lower than 5 MPC, in conditions of moderate salinity.

In the field experiment, non-saline and moderate saline (0.3% NaCl) soils, containing Ni^{2+} and Cu^{2+} in the concentration ratios of 50:100, 50:250, 50:500, 100:100, 100:250, 100:500, 250:100, 250:250, 250:500 mg kg^{-1} of soil were used. Natural soil was used as the control; its analysis showed the content of Cu at 42 mg kg^{-1} of soil, and Ni at 66 mg $kg^{-1}$of soil.

Corn was cultivated in natural conditions from May to August. Ripe corn ears were cut and roots were removed from the soil. The content of Ni and Cu was determined in roots, leaves, stems and ears. The results of the analyses are shown in Figures 4-6. In each figure, the diagrams of Cu and Ni distribution in the plant parts relative to the metal concentration ratio in non-saline and moderate saline soils are presented. An analysis of the data presented in the diagrams allowed us to identify patterns of phytoextraction process and metal distribution in the parts of corn.

In non-saline soil with a stable content of Cu (50 mg kg^{-1}), an increase in the nickel concentration from 100 to 500 mg kg^{-1} led to the growth of nickel concentration in biomass (mg kg^{-1}): in roots – from 5.6 to 180; in stems – from 3.6 to 174; in leaves – from 3.5 to 102. It was noted that the maximum quantity of Ni accumulated in biomass when the Cu:Ni ratio in soil was 50:500 mg kg^{-1}. In the case of Cu present in soil in a higher concentration, the accumulated quantity of Ni was lower.

At a stable content of Cu (100 mg kg^{-1}), an increase in the nickel concentration from 100 to 500 mg kg^{-1} led to the growth of nickel concentration in biomass (mg kg^{-1}): in roots – from 7.8 to 74; in stems – from 9.5 to 101; in leaves – from 4.0 to 54. In this case, the Cu concentration in corn did not change alongside an increasing nickel concentration.

At a stable content of Cu (250 mg kg^{-1}), a change in the nickel concentration from 100 to 500 mg kg^{-1} led to the growth in the nickel content of biomass (mg kg^{-1}): in roots – from 6.3 to 81; in stems – from 5.2 to 73; in leaves

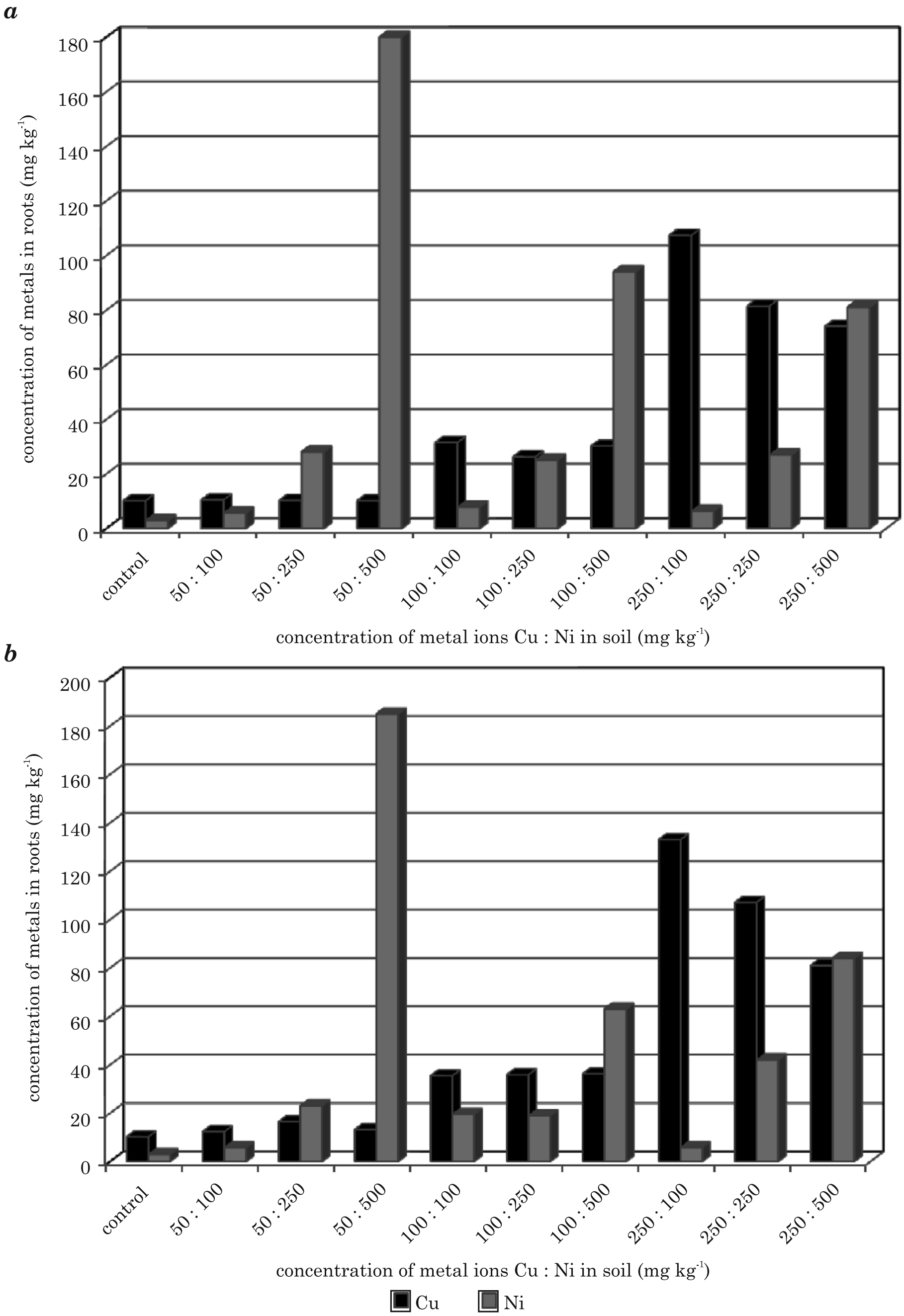

Fig. 4. Accumulation of metals in roots of corn (mg kg^{-1} of dry biomass) during field experiment: *a* – non-saline and *b* – saline (0.3% NaCl) soils

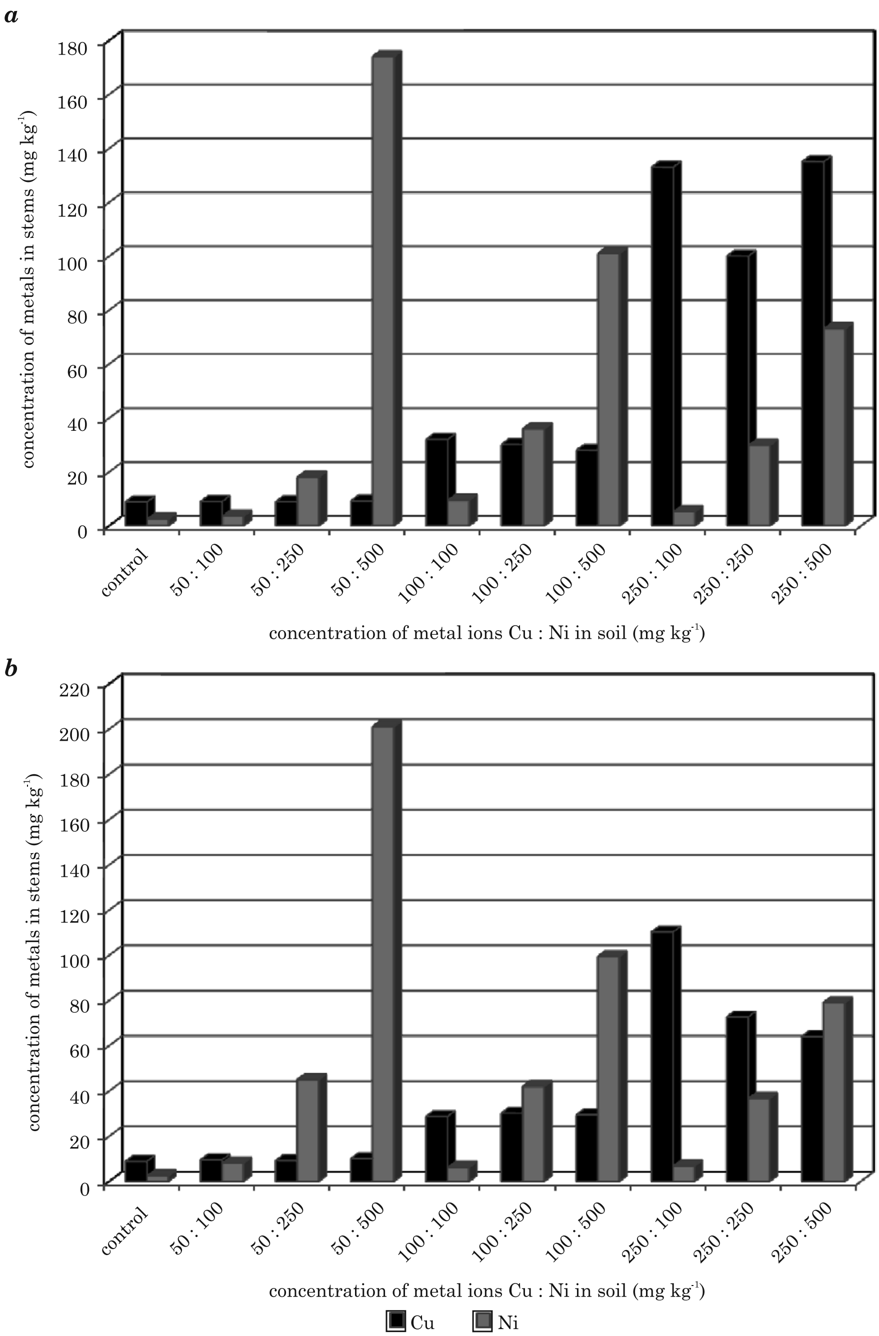

Fig. 5. Accumulation of metals in stems of corn (mg kg^{-1} of dry biomass) during field experiment: *a* – non-saline and *b* – saline (0.3% NaCl) soils

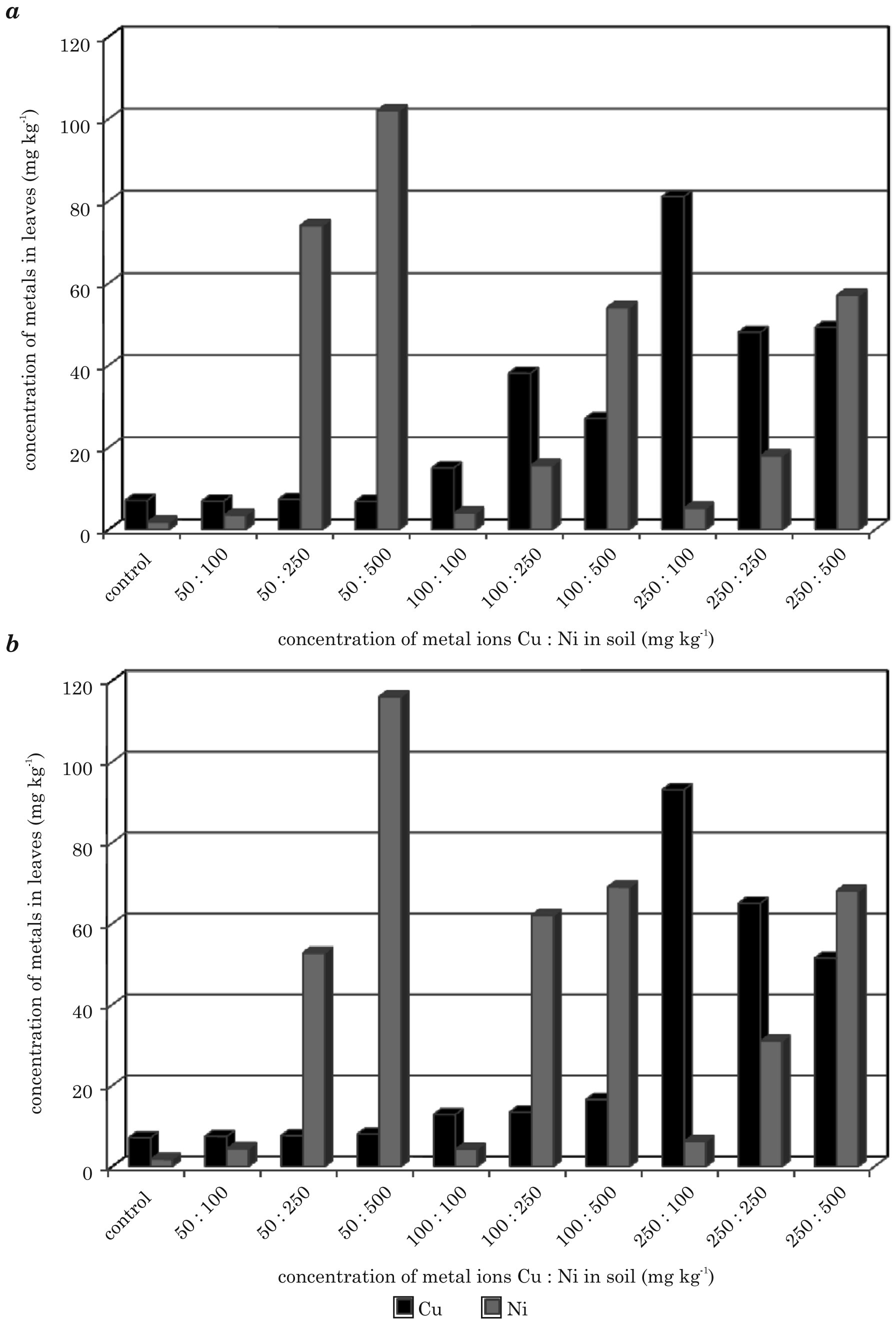

Fig. 6. Accumulation of metals in leaves of corn ordinary (mg kg^{-1} of dry biomass) during field experiment: *a* – non-saline and *b* – saline (0.3% NaCl) soils

– from 5.2 to 57. An increase in the Ni concentration in soil from 100 to 500 mg kg^{-1} led to a decrease in the Cu content accumulated in roots – from 107.3 to 74; in stems – from 133 to 135; in leaves – from 81 to 42.9.

In the case of corn grown in moderately saline soil, the Cu content in corn roots tended to be higher, it was lower but in leaves and stems than in the corresponding organs of corn grown in non-saline soil. It was noted that at the maximum metal pollution of soil (Cu^{2+}:Ni^{2+} = 250:500 mg kg^{-1}) the total quantity of metals accumulated by corn was higher in corn grown in moderately saline soil than in non-saline soil. Thus, soil salinity promotes the process of phytoextraction of Cu and Ni.

The diagrams clearly demonstrate that with an equal content of Cu and Ni in soil (100:100; 250:250 mg kg^{-1}) the amount of copper accumulated in plants is over three-fold higher than that of nickel. Therefore, copper is a more preferable metal for the plant during phytoextraction. These data are consistent with the results of the laboratory tests.

The accumulation of Cu and Ni in the corn ears of the experimental plants in comparison with the control was not observed. Thus, corn ears are safe for consumption.

CONCLUSIONS

The main conclusions of the present study can be summarized as follows:

In the laboratory experiments:

- Sunflower (*Heliantus annus* L.) and corn (*Zea mays* L.) are resistant to a high concentration of copper and nickel ions (copper – 1000 mg kg^{-1}, nickel – 2000 mg kg^{-1}), and NaCl (up to 0.6%) in the soil.
- The plants' ability to extract Cu and Ni ions significantly decreased when metal concentrations in soils were higher than 5 MPC (Ni^{2+} – 500 mg kg^{-1}, Cu^{2+} – 250 mg kg^{-1}).
- Phytoextraction of metals by both plants depended on the salt content in soil. In the presence of 0.3% NaCl, the quantity of extracted copper increased up to 13%, and nickel – up to 20% in comparison with non-saline soil. In the presence of 0.6% NaCl, the quantity of extracted copper decreased by 22-50%, and nickel – by 25-40% compared with moderately saline soil (0.3% NaCl).
- After two-week cultivation of corn, it was shown that most of the metals accumulated in roots; 0.3% NaCl salinity of soil promoted more active transport of metal ions from roots to shoots.

In the field experiments (corn was cultivated in soils with 0.3% NaCl contaminated with Cu and Ni – the content of each metal was no more than 5 MPC – in different concentration ratios):

– Salinity of soil promoted higher accumulation of heavy metals.
– Accumulation and distribution of the metals in the parts of corn depended on the ratio of the metals in the soil.
– During the whole growing period, each of the metals was evenly distributed in roots, stems and leaves of corn, without penetrating into ears.
– At the co-occurrence of Cu and Ni in soil and their equal content, copper was accumulated in plants more effectively.
– At the end of the growing season, there were no metals in corn ears, which indicates the possibility of using ears as food.

Generally, we demonstrated that corn (*Zea mays* L.) and common sunflower (*Heliantus annus* L.) can be used for phytoremediation of soils contaminated with nickel and copper and salinated by sodium chloride.

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