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ORIGINAL ARTICLE

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NICKEL CONTENT IN FIELD CROP SEEDS AND AGRICULTURAL SOIL IN CENTRAL SERBIA

ABSTRACT: Nickel (Ni) is an essential nutrient for animals and it has an important role in many physiological and biochemical processes in higher plants. At the same time, it belongs to the group of potentially toxic elements (PTEs). The aim of this study is to determine Ni concentrations in the soil-plant relationships between the main crops and agricultural land in Central Serbia. A total of 71 bulked soil samples are taken from the topsoil at the depth of 0–30 cm in an area belonging to 6 statistical districts of Central Serbia. A total of 71 seed samples are collected during harvest as an average sample of seed from each observed plot, of which 26 are corn, 19 sunflower, 17 wheat, and 9 soybean samples. Analysis of the collected samples includs the main soil parameters and Ni total and available concentrations in soil, as well as Ni total concentration in seeds. The median value of total Ni concentration in soil is 44.8 mg kg^{-1}, close to MAC. The median nickel concentration in wheat and corn seeds is 0.5 mg kg^{-1}, while soybean and sunflower seeds have higher median Ni content of 8.40 and 10.26 mg kg^{-1}, respectively. Bioaccumulation factors in seeds (BAF) in the present study ranges from 0.013 (corn) to 0.256 (soybean). According to statistically significant differences, all crops have equal total Ni_T concentration in soil, while the available Ni_A concentration differs in soils under corn and sunflower cultivars. Based on Ni concentration in seed and BAF, two groups are distinguished − the group of soybeans and sunflowers with higher Ni content and the group of wheat and corn with lower Ni content in seed. The obtained differences confirm that plant species have a significant role in the bioaccumulation of Ni. The determined BAF parameter is in a statistically significant negative correlation with the total Ni content in soil in all observed crops except maize. However, the BAF parameter for maize alone is in a statistically significant negative correlation with the readily available Ni concentration in the soil. The obtained correlations indicate that higher Ni concentration in soil causes lower Ni concentration in seeds, which might be due to the activation of plant defense mechanism to preserve the reproductive organs – seeds – from

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harmful effects. Based on the obtained results, Ni concentration in seeds of the main field crops in Central Serbia is safe for feed and food usage. Increased content of Ni found in agricultural soils in Central Serbia requires constant monitoring for maintaining sustainable agriculture production.
KEYWORDS: nickel, field crops, soil, seed

INTRODUCTION

The content of hazardous and harmful substances in soils requires constant monitoring due to the negative impact of such substances on crops, as well as their presence in the food chain.

Monitoring potentially toxic elements (PTE) is conducted to assess soil contamination by agrochemicals. Also, soil conservation is crucial to the establishment of sustainable agriculture. Numerous studies examining possible soil contamination by PTE indicate a high content of nickel (Ni) in Serbian soils as a result of soil geochemical origin (Mrvić, 2009; Albanese et al., 2015).

Ni is an essential nutrient for animals and a beneficial element for higher plants. As a cofactor for urease and hydrogenase, Ni plays a significant role in the enzyme-catalyzed metabolic processes of higher plants. According to Drzewiecka et al. (2012), Ni is an important metal in plant metabolism and a cofactor of numerous metalloenzymes. On the other hand, nickel causes toxic effects on plants in relatively small doses. Although the increased content of nickel in Serbian soils results from soil geochemical origin, a detailed investigation of Ni content should be conducted, including its correlation with the main soil properties and different plant species.

Ni is relatively stable in an aqueous solution. In soil solution, Ni may exist as aqueous Ni^{2+}, complexed with inorganic and organic ligands, and/or associated with suspended mineral colloids, where the organic complexes may be dominant in soil solution (Adriano, 2001). Compared to other metals, nickel shows exceptional mobility from soil to surface plant parts, which can directly affect plant photosynthetic activity (Huillier et al., 1996).

The establishment of a critical level of Ni in soil and plant, from the aspect of both deficiency and toxicity, is still the subject of discussion by many authors, due to the unexplained essentiality of nickel for plants and animals, and Ni is required only in ultra-trace amounts. In addition, Ni is comparatively abundant in most soils and its deficiency is a very rare condition, even where bioavailability is low due to high carbonate, sesquioxide, and organic matter content (Adriano, 2001). According to Kabata-Pendias and Pendias (2001), the toxic effects of nickel on plant growth and development ranged from 10 to 100 mg kg^{-1} dry weight of soil, indicating the need for a more detailed examination of the effect of nickel on economically important plant species. Considering that Serbian plant production is mainly focused on maize, wheat, soybean, and sunflower, it must be determined how the readily available nickel is adopted by these plant species, as well as the extent to which nickel is toxic to plants.

This study aims to determine the concentrations of Ni in the soil-plant relationships between the main crops and agricultural land in Central Serbia.

MATERIALS AND METHODS

Sample collection and processing

Field trials were carried out in the second half of 2018. The locations of collected soil samples are shown in Figure 1 and belong to 6 statistical districts of Central Serbia: East, Bor, South, West, Belgrade, and Central District. A total of 71 bulked soil samples are taken from topsoil at the depth of 0–30 cm, using a probe drill. One composite soil sample represented 15–25 subsamples from production plots (up to 5 ha area).

Field crops are sampled during harvest as an average sample of seed from each observed plot. A total of 71 seed samples are collected, of which 26 samples are corn, 19 sunflower, 17 wheat, and 9 soybeans.

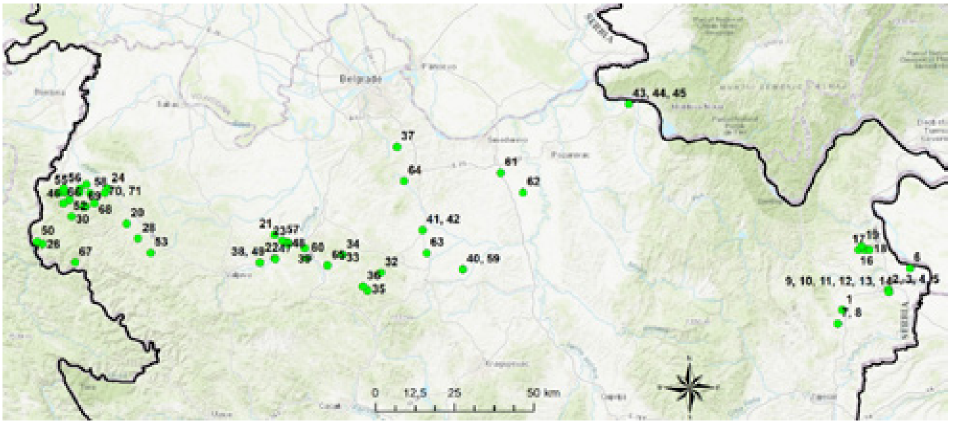

Figure 1. The layout of observed locations

Laboratory analyses

The soil samples are air-dried at room temperature, milled, and sieved to <2 mm particle size, following ISO 11464:2006. Particle size distribution in the <2 mm fraction is determined by the pipette method (Van Reeuwijk, 2002). The size fractions are defined as clay (<2 µm), silt (2–20 µm), fine sand (20–200 µm), and coarse sand (200–2000 µm). The applied methods are as follows: the pH value (ISO 10390:2005), the free $CaCO_3$ content (ISO 10693:1995), the organic matter content (OM) (ISO 14235:1998), the total N (ISO 13878:1998), and the total organic C (TOC) (ISO 10694:1995). Readily available phosphorus

(P_2O_5) and available potassium (K_2O) are extracted by the AL method (Egner and Riehm, 1955) and measured by the means of spectrophotometry and flame photometry, respectively.

The samples are analyzed for the total content of Ni after the soil microwave digestion in concentrated acid solution (5:1 HNO_3/H_2O_2, and 1:12 solid/solution ratio). In parallel, the bioavailable nickel concentration in soil is determined using buffered EDTA extraction solutions according to extraction protocols for IRMM BCR reference materials CRM-484 (5 g soil/50 ml EDTA concentration 0.05 $molL^{-1}$ pH=7.00).

The plant samples are air-dried and ground in a mill to extract the plant material. As moisture content is determined gravimetrically, the reported results refer to dry mass. Plant materials are analyzed for total Ni content after the microwave digestion of the samples in a concentrated acid solution (0.5 g of sample material in a digestion solution comprised of 10 ml HNO_3 + 2 ml H_2O_2, Vt = 50 ml).

The concentration of nickel in prepared soil and plant samples is determined by ICP-OES (Vista Pro-Axial, Varian) following the US EPA method 200.7:2001.

Quality assurance and quality control (QA/QC) assessments are conducted using certified reference materials IRMM ERM-CC141 (loam soil), IRMM BCR-484 (sewage sludge amended terra rossa soil), and SRM1515 (apple leaves); for total, available Ni concentration in soil and plant matrix, respectively. The percentage of recovery, defined as the ratio of measured concentrations and certified values of two reference materials, ranged from 87% to 111%, which provided adequate analytical accuracy and precision.

The results of the plant material and soil analysis are calculated on dry matter (DM).

Calculation of bioaccumulation factor

To estimate the nickel uptake rates by studied crop seeds from the soil, the bioaccumulation factors (BAF) are used, defined as flowing equation:

$$BAF = \frac{\text{Ni concentration in seed } [mg \cdot kg^{-1}]}{\text{Total Ni concentration in soil } [mg \cdot kg^{-1}]}$$

Statistical analysis

Data are statistically processed by analyzing the main descriptive parameters for each element. Correlations between all the examined parameters are determined, while the statistical differences between the tested Ni contents in plants and soil are determined by Duncan's multiple range test.

All statistical analyses are performed using STATISTICA for Windows version 13 (TIBCO, 2018). Statistical parameters are shown in tables.

RESULTS AND DISCUSSION

Soil characterization and nickel concentration in soil

In the examined samples, the distribution of soil mechanical fractions differs among districts, as well as within each district. Texture classes range from light sandy to heavy clay, but soils with a medium mechanical composition still dominate, with a slight dominance of the silt fraction (Table 1). The soil pH values vary from plot to plot, both within one district and between districts. The potential pH values (in 1M KCl solution) range from acidic (pH 4.93) to slightly alkaline (pH 8.20), while the median value is 6.63 that belongs to a neutral class (Table 1). Since the pH reaction of the soil is highly correlated with the $CaCO_3$ content, the obtained results are very similar to the pH distribution. According to the results of the research, weak calcareous and non-calcareous soils are the most common, while a strong calcareous class is determined in a small number of plots (Table 1). The contents of organic matter (OM) and total organic carbon in soil (TOC) are also highly correlated, so the obtained results show similar distribution between the soil classes. The content of OM ranges from 0.81 to 6.57%, but the prevailing OM content does not exceed 3%, which is characteristic of low humus soils (Table 1). Based on the median of all results obtained for total nitrogen, the examined soils are moderately supplied with total nitrogen (Table 1). The content of readily available phosphorus ranges from very low (ameliorative class) to extremely high (toxic) content. Most of the samples are classified as poor in phosphorus. The content of readily available potassium ranges from low through very high to harmful class. Most of the tested samples are classified in the optimal class (Table 1). A determined wide range of phosphorus and potassium concentration in soil, as well as high statistical variation between soil samples (Table 1) confirm that P_2O_5 and K_2O content is strongly affected by inadequate fertilization practices.

Table 1. Descriptive statistics of the observed soil parameters

Parameter	Aver. value	Median value	MIN	MAX	ST DEV	CV [%]	SE
Coarse sand[%]	6.10	2.46	0.70	37.03	8.028	131.63	0.953
Fine sand [%]	33.55	31.76	11.11	65.30	11.541	34.40	1.370
Silt [%]	31.97	35.04	6.88	47.12	8.670	27.12	1.029
Clay [%]	28.39	28.84	6.76	62.08	11.355	40.00	1.348
pH in H_2O	5.61	5.28	3.79	7.62	1.203	21.45	0.143
pH in 1MKCl	6.63	6.32	4.93	8.20	1.039	15.67	0.123
$CaCO_3$[%]	1.21	0.25	0.00	12.27	2.578	213.74	0.306
OM [%]	2.45	2.22	0.81	6.57	1.198	48.95	0.142
TOC [%]	1.71	1.41	0.09	5.93	1.188	69.33	0.141
Total N [%]	0.192	0.164	0.061	0.574	0.106	55.23	0.013
P_2O_5[mg $100g^{-1}$]	11.56	7.30	0.90	182.00	21.793	188.49	2.586
K_2O [mg $100g^{-1}$]	20.57	20.19	5.56	72.74	10.027	48.75	1.190
Ni_T[mg kg^{-1}]	50.34	44.82	19.23	113.40	23.028	45.74	2.733
Ni_A[mg kg^{-1}]	5.71	5.13	0.84	16.33	3.802	66.61	0.451

Values for total nickel content Ni_T in soil obtained in the present study ranges from 19.2 (location 17) to 113.4 mg kg^{-1} (location 69) (Figure 1, Table 1). The maximum allowable concentration – MAC (OG 23/1994) is 50 mg kg^{-1}, and 30 soil samples out of 71 observed in the present study have a higher concentration than the MAC threshold. The median value obtained in the study is 44.8 mg kg^{-1} (Table 1). The median exceeds the listed background concentration for European soils (<35 mg kg^{-1}) (Houskova and Montanarella, 2006). Based on the GEMAS project, the median for Europe is 14.7 mg kg^{-1} (Albanese et al., 2015), which is much lower than the value obtained in this study.

The available Ni content in EDTA Ni_A detected in all samples ranges from 0.8 (location 21) to 16.3 mg kg^{-1} (location 57), with the median value of 5.1 mg kg^{-1} (Figure 1, Table 1). The percentage of accessible content in the total content is a good indicator of soil pollution and it ranges from 1.4 to 22.7%. Out of eight observed samples with a share higher than 20%, seven have a total content above MAC. According to the observed statistics, all studied regions have a median in the range of 40–50 mg kg^{-1}, except for the southern region where the median is 34.5 mg kg^{-1}. It has been pointed out that the soils in Serbia have increased nickel content due to the geochemical origin of soils formed from the parent substrate rich in nickel (Dozet et al., 2011). The present study is therefore in line with the previously conducted research.

According to the established statistically significant correlation (data not shown), the total concentration of Ni is positively correlated with clay content but negatively correlated with fine sand content. In addition, total Ni is positively correlated with organic matter content. Contrary to the expectations of this study, a lower pH reaction has not been proven to increase the content of Ni, according to the established positive correlation between Ni_T and pH values, which is attributed to the predominantly acidic reaction of the observed samples.

Nickel concentration in seed

The concentration of nickel in most natural vegetation is about 0.5 mg kg^{-1}, which is the median value for wheat and corn in this study (Table 2). Soybean and sunflower seeds have a much higher Ni content of 8.40 and 10.26 mg kg^{-1} median value, respectively. Average contents of Ni in cereal grains vary from 0.34 to 14.6 mg kg^{-1} (Kabata-Pendias and Mukherjee, 2007) in different countries, which is in accordance with the results of the present study. The highest value of 19.4 mg kg^{-1} (Table 2) is found in soybeans at location 40 (Figure 1), originating from soils where nickel is below the MAC (Ni_T=36.4 and Ni_A=5.2 mg kg^{-1}). The most variable results between the analyzed samples are found in corn, while the other crops have similar variations in results (Table 2). According to Adriano (2001), the critical level of Ni deficiency in plants is <0.1 mg kg^{-1}, while sufficient levels in plants vary in a wide range from 0.01 to 10 mg kg^{-1}. Therefore, all tested crops in this study have sufficient nickel content. The phytotoxic Ni concentrations vary widely among plant species and cultivars, reported to range from 40 to 246 mg kg^{-1} (Kabata-Pendias and Pendias 2001). According to Kastori (1997), the critical toxic concentrations of Ni in plants amount to 20 and 30 mg kg^{-1}, respectively. Therefore, no toxic effects of Ni on plants are expected in the present study.

According to the rulebook on the quality of feed (OG RS 39/2016), there are no special restrictions for the nickel content. According to the rulebook on the quality of food (OG RS 90/2018), there is a limit of 0.5 mg kg^{-1} for Ni content in oils, fats, margarine, and related products. Based on all the obtained results, Ni concentration in the seed of the main field crops in Central Serbia is safe for feed and food usage.

Ni is required in a nutrient solution to prevent the accumulation of toxic concentrations of urea in not only urea-fed but also mineral N-fed (nitrate, ammonium) or N-fixing soybean (Kutman et al., 2013). In this study, soybean seeds are produced by growing plants in nutrient solutions containing different Ni levels, and their urease activities are measured. According to the obtained results, seeds with Ni concentrations vary between 0.04–8.32 mg kg^{-1}. Depending on the Ni concentration, a significant difference is observed between seed urease activities and the increased rates of nickel supply increases seed yield by up to 25%.

The results obtained for BAFs range from 0.004 (corn) to 0.866 (sunflower) (Table 2). According to BAF results, the observed plant species have no hyperaccumulation characteristics (BAF>1). The median value of the determined bioaccumulation factors (BAF) in the present study coincides with Ni concentrations in seed in the following order (Table 2):

BAF corn < BAF wheat < BAF sunflower < BAF soybean.

The obtained results point that sunflower and soybean have tenfold higher potential for Ni accumulation in seeds, compared to corn and wheat (Table 2).

Table 2. Descriptive statistics of Ni concentration in plant seeds and of bioaccumulation factors

Parameter	Aver. value	Median value	MIN	MAX	ST DEV	CV [%]	SE
Ni wheat [mg kg^{-1}]	0.813	0.500	0.500	1.658	0.449	55.17	0.109
BAF wheat	0.020	0.019	0.005	0.052	0.014	68.73	0.003
Ni corn [mg kg^{-1}]	0.608	0.500	0.500	3.300	0.549	90.36	0.108
BAF corn	0.013	0.012	0.004	0.036	0.007	50.85	0.001
Ni soybean[mg kg^{-1}]	9.981	8.405	4.690	19.420	4.896	49.06	1.632
BAF soybean	0.256	0.157	0.082	0.563	0.191	74.52	0.064
Ni sunflower[mg kg^{-1}]	8.937	10.260	0.500	17.860	5.109	57.17	1.172
BAF sunflower	0.255	0.126	0.006	0.866	0.244	95.81	0.056

Aver. – Average value; MIN – Minimum value; MAX – Maximum value; ST DEV – Standard deviation; CV – Coefficient of variation; SE – Standard error of the arithmetic mean

The present study investigates the statistically significant differences between Ni concentration in soil, plant, and BAF parameters in the observed plant species (Table 3). The first important observation is that all crops have equal total Ni_T concentration in soil. According to available Ni_A concentrations in soil, mutual differences are found between soils under maize and sunflower. According to Ni concentration in seed and BAF, two groups are clearly distinguished – the group of soybeans and sunflowers with higher Ni content and the group of wheat and corn with lower Ni content in seed (Table 3). The obtained differences confirm that plant species have a dominant role in the bioaccumulation of Ni, as documented in previous research (Sheoran et al., 2016).

Table 3. The average value and statistical difference of Ni concentration in soil and plant for observed crops species

Crops species	Ni_T [mg kg^{-1}] in soil	Ni_A[mg kg^{-1}] in soil	Ni [mg kg^{-1}] in seed	BAF
Wheat	48.1^{a}	5.2^{ab}	0.813^{b}	0.020^{b}
Corn	50.8^{a}	7.3^{a}	0.608^{b}	0.013^{b}
Soybean	50.2^{a}	5.0^{ab}	9.981^{a}	0.256^{a}
Sunflower	51.9^{a}	4.4^{b}	8.937^{a}	0.255^{a}

Values marked with the same letter do not differ in statistical significance (according to Duncan's multiple range test. $p \leq 0.05$)

Table 4. Correlations between BAF, Ni concentration in plant and soil for observed crops species

	Parameter	Ni in seed	Ni_T in soil	Ni_A in soil	BAF
Wheat	Ni in seed	1.000	-0.114^{ns}	-0.066^{ns}	0.834**
	Ni_T in soil		1.000	0.585*	-0.565*
	Ni_A in soil			1.000	-0.359^{ns}
	BAF				1.000
Maize	Ni in seed	1.000	0.358^{ns}	-0.034^{ns}	0.694**
	Ni_T in soil		1.000	0.630**	-0.367^{ns}
	Ni_A in soil			1.000	-0.579**
	BAF				1.000
Soybean	Ni in seed	1.000	-0.543^{ns}	-0.230^{ns}	0.944**
	Ni_T in soil		1.000	0.597*	-0.754*
	Ni_A in soil			1.000	-0.388^{ns}
	BAF				1.000
Sunflower	Ni in seed	1.000	-0.443^{ns}	-0.182^{ns}	0.821*
	Ni_T in soil		1.000	0.782**	-0.730*
	Ni_A in soil			1.000	-0.424^{ns}
	BAF				1.000

** $p \leq 0.01$ significantly correlated; * $p \leq 0.05$ significantly correlated; ns – no statistical signification

Concerning soil-plant nickel distribution relationships, the determined correlations are shown in Table 4. A significant positive correlation is found between soil total and available Ni concentration, as well as between Ni concentration in seed and BAF, which is expected. Ni concentration in seeds is not significantly correlated with either total or available Ni concentration in soil in any of the observed crop species, highlighting the importance of the bioaccumulation factor (BAF).

Determined parameter BAF is in statistically significant negative correlation with total Ni content in soil for all observed crops, except maize, where BAF is negatively correlated with available Ni concentration in soil (Table 4). The obtained correlations indicate that higher Ni concentration in the soil causes lower Ni concentration in the seed. This might be due to activation of the plant defense mechanisms for preservation of its reproductive organs – seeds, in this case – from the harmful effects. In future research, these relationships need to be examined in detail. The Ni uptake by plants from the serpentine soils, which geochemically contain enormously high Ni concentrations, have been widely investigated and based on these studies. The uptake and translocation of Ni primarily depend on the plant species, where some serpentine endemic species have adapted and act as Ni hyperaccumulators with the concentration of even 1,000 mg kg^{-1} in plant tissue (Milić et al., 2021). However, non-endemic serpentine plant species generally uptake low Ni content compared to the uptake of other PTEs, although they grow in soil with such high Ni content (Freitas et al., 2004; Bani et al., 2010; Vicić et al., 2014; Tomović et al., 2017; Milić et al., 2021). The reason for the lower accumulation of Ni in plants, despite the high content of Ni in the soil medium, can be the activation of defense mechanisms for the accumulation of nickel in plant tissue.

CONCLUSION

The median value of total Ni concentration in soil under main field crops in Central Serbia is 44.8 mg kg^{-1}, which is close to MAC. The median concentration of Ni in wheat and corn seeds is 0.5 mg kg^{-1}, while soybean and sunflower seeds have much higher Ni content of 8.40 and 10.26 mg kg^{-1}median value, respectively. The median value of determined bioaccumulation factors (BAF) in the present study coincides with Ni concentration in seed and ranges from 0.013 (corn) to 0.256 (soybean). Therefore, the observed plant species have no hyperaccumulation characteristics. The obtained results indicate a tenfold higher Ni accumulation potential in sunflower and soybean seed compared to corn and wheat. According to statistically significant differences, all crops have equal total Ni_T concentration in soil, while the available Ni_A concentration in soil under corn and sunflower is different. According to Ni concentration in seed and BAF, two groups are clearly distinguished − the group of soybeans and sunflowers with higher Ni content and the group of wheat and corn with lower Ni content in seed. The obtained differences confirm that plant species have a dominant role in the bioaccumulation of Ni. Ni concentration in seeds is not significantly correlated with either total or available Ni concentration in the soil in any of the observed crops. The determined BAF parameter is in a statistically significant negative correlation with total Ni content in the soil in all observed crops except maize, where BAF is negatively correlated with available Ni concentration in soil. The obtained correlations indicate that higher Ni concentration in soil caused lower Ni concentration in seed, due to the activation of plant defense mechanisms for preservation of its reproductive organs, i.e. seeds, from harmful effects. In future research, these relationships need to be examined in detail.

Based on the obtained results, the main field crops in Central Serbia have safe Ni concentration levels in seed intended for feed and food usage. Increased content of Ni in agriculture soils of Central Serbia requires permanent monitoring aiming at sustainable agriculture production.

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ОРИГИНАЛНИ НАУЧНИ РАД

САДРЖАЈ НИКЛА У СЕМЕНУ РАТАРСКИХ УСЕВА И ПОЉОПРИВРЕДНОМ ЗЕМЉИШТУ ЦЕНТРАЛНЕ СРБИЈЕ

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РЕЗИМЕ: Никал је есенцијални хранљиви елемент за животиње и има важну улогу у бројним физиолошким и биохемијским процесима виших биљака, али истовремено припада групи потенцијално токсичних елемената (ПТЕ). Циљ овог истраживања био је да се утврде концентрације Ni у релацији земљиште–биљка између главних ратарских биљних врста и пољопривредног земљишта за централну Србију. Укупно је узето 71 узорак земљишта из горњег слоја земљишта 0–30 cm, с подручја шест статистичких округа централне Србије. Прикупљено је укупно 71 узорак семена током жетве као просечан узорак семена са сваке посматране парцеле, од чега је 26 узорака било семе кукуруза, 19 сунцокрета, 17 пшенице и девет соје. Прикупљени узорци анализирани су на основне параметра земљишта и укупну и приступачну концентрацију никла у земљишту, као и укупну његову концентрацију у семену. Вредност медијане за укупну концентрацију никла у земљишту била је 44,8 mg kg^{-1}, што је близу вредности МДК. Средња концентрација никла у семену пшенице и кукуруза била је 0,5 mg kg^{-1}, док је семе соје и сунцокрета имало знатно већи садржај Ni од 8,40 односно 10,26 mg kg^{-1}. Фактори биоакумулације у семену (BAF) у овој студији кретали су се од 0,013 (кукуруз) до 0,256 (соја). Према статистички значајним разликама, све ратарске биљне врсте имале су једнаку укупну концентрацију Ni_T у земљишту, док су се према приступачној концентрацији Ni_A у земљишту, међусобно разликовала земљишта под кукурузом и сунцокретом. На основу концентрације Ni у семену и BAF-a, јасно се издвајају две групе: у једној групи су соја и сунцокрет са већим садржајем Ni, док су у другој групи пшеница и кукуруз са нижим садржајем Ni у семену.

Добијене разлике потврђују да биљне врсте имају значајну улогу у биоакумулацији Ni. Утврђени параметар BAF био је у статистички значајној, негативној корелацији са укупним садржајем Ni у земљишту за све посматране усеве, осим кукуруза. Међутим, вредност BAF-а је само за кукуруз била у статистички значајној, негативној корелацији са приступачном концентрацијом Ni у земљишту. Добијене корелације указују да је већа концентрација никла у земљишту узроковала његову мању концентрацију у семену, вероватно услед активирања одбрамбених механизама биљака за очување репродуктивних органа – семена, од штетних утицаја. На основу свих добијених резултата, главне ратарске биљне врсте у централној Србији имале су безбедну концентрацију никла у семену за сточну и људску храну. Повећан садржај никла у пољопривредном земљишту централне Србије захтева стално праћење у циљу одрживе пољопривредне производње.
КЉУЧНЕ РЕЧИ: никал, ратарске културе, земљиште, семе