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NATALIIJA O. RYZHENKO*, S. V. KAVETSKY**,
VOLODYMYR M. KAVETSKY*

HEAVY METALS (Cd, Pb, Zn, and Cu) UPTAKE BY SPRING BARLEY IN POLLUTED SOILS

Abstract. Accumulation of Cd, Pb, Zn, Cu (HM) by spring barley (Hordeum vulgare L.) from sod podzolic sandy loam and chernozem soils, impacted by heavy metals pollution in the soils, is studied in the article. The aim of study has been to determine spring barley bioaccumulation capacity impacted by the HM pollution with the high level of Cd, Pb, Zn, Cu concentration in soils. The HM concentration diapason caused biomass reduction – the scope of toxic tolerance was obtained. The range of contaminants concentration in soil, which caused the plant biomass reduction, from the beginning to plants death – the scope of toxic tolerance, is the index of a species reaction on selected xenobiotic. It shows: "threshold" concentration of a contaminant that caused a plant biomass inhibition; toxic process development and the correlation between contaminants concentration in soil and/or plant and the plants inhibition; the concentration that caused the plant death. Spring barley accumulation indexes of the studied metals were calculated. Relevant scopes of the plant-uptake index for each metal were calculated. Dynamics of the toxic process development of spring barley as impacted by the pollution in the break-down by studied metals were observed on two different soils. Toxic process dynamic evaluation gives the possibility to simulate concentration of the trace metal in plants, concentration of available forms of these elements in soils, and also contamination level (content of metals) that caused plants height and plant weight reduction by 10%, 50% and 90%.

Heavy metals (HM) are among the most important contaminants in the natural environment [1]. Investigation of heavy metals up-take by plant in polluted soil is important because pollutants concentration in crops determines the quality of agricultural products. Metal uptake by plants depends on the bioavailabil-

* N.O. Ryzhenko, DSc., Prof. V.M. Kavetsky, DSc.; Faculty of Natural Sciences, National University of Kyiv-Mohyla Academy, 2 Skovoroda Street, office 3-216, Kyiv, 04655.

** S.V. Kavetsky, DSc., Faculty of Agricultural Chemistry and Soil Science, National Agricultural University of Ukraine, Geroiv Oborony 17 building 2, Kyiv, 03041, Ukraine.

ity of the metal in the soil solution, which in turn depends on the retention time of the metal, as well as the interaction with other elements and substances in the solution. Furthermore, when metals have been bound to the soil, the pH, redox potential, and organic matter content will all affect the tendency of the metal to exist in ionic and plant-available form. Plants will affect the soil through their ability to lower pH and oxygenate the sediment, which affects the availability of the metals [1, 2]. The rate of plant up-take of the HM depends on the physical and chemical properties of the metal, soil properties (organic matter content, and other agro-physical properties) and the crops bioaccumulation capacity [1-4] Bioaccumulation capacity and the HM toxic effects are characterised by the plant up-take index [5-8]. The HM bioaccumulation capacity of crops is often considered during soil remediation measure [1]. Contamination of soils with heavy metals changes phytometric parameters of plants depending on the contaminants concentration in root zone and, as a result of that, in plant tissue [9, 10]. Plants can tolerate high heavy metals concentration from soil by means of two basic strategies [10]. The first strategy is called accumulation strategy, where a metal can accumulate in plants at both high and low concentration from soil [10]. These plants are capable of rendering the metals in various ways, for instance, by binding them to cell walls, compartmentalising them in vacuoles or complexing them to certain organic acids or proteins [10]. The second strategy is called exclusion strategy, where transport of heavy metals in shoots and leaves is limited over a wide range of metal concentrations in soil. Some of the plants make stable metal complexes in the root cells to prevent metal translocation from the roots to above-ground tissues. Some metals are essential for plant growth (Fe, Mn, Zn, Cu, Mg, Mo, and Ni). Some metals with unknown biological function (Cd, Cr, Pb, Co, Ag, Se, Hg) can also be accumulated [1,6]

However, phytometric parameters change depending on the level of the HM concentration in the root-containing soil layer [1, 3]. The HM contamination of the root soil layer usually leads to the rise of trace elements plant uptake and biomass reduction [6]. The HM concentration diapason causes biomass reduction – the scope of toxic tolerance can serve as the index of metal's toxicity for selected plant species. The range of contaminants concentration in soil, which causes the plant biomass reduction, from the beginning to plants death – the scope of toxic tolerance, is the index of a species reaction on selected xenobiotic [9,11]. It shows:

– "Threshold" concentration of a contaminant that causes a plant biomass inhibition.

– Toxic process development and the correlation between contaminants concentration in soil and/or plant and the plants inhibition.

– Concentration that causes the plant death.

The investigation, to a certain extent, was dedicated to adaptation of the well-known Shelford curve of ecological tolerance [11–13] to reaction of spring barley on selected trace elements contamination (Fig. 1). On the other hand, it did not study the whole scope of ecological tolerance curve but only the toxic effect of Cd, Pb, Zn, Cu on spring barley. That scope is shown on the curve as the experimental area (Fig. 1).

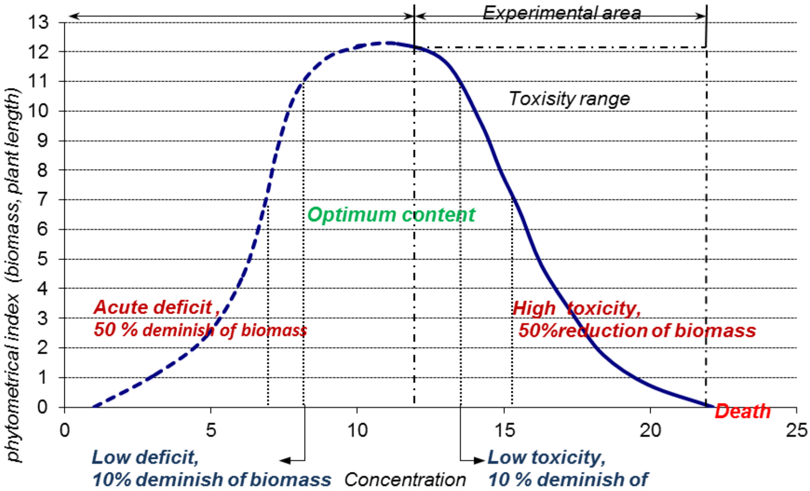

Fig. 1. Ecological tolerance (*by Shelford, V. E*) [11–13] .

In our investigation spring barley bioaccumulation capacity was studied as impacted by the HM pollution with the high level Cd, Pb, Zn, and Cu concentration in soils.

Spring barley (*Hordeum vulgare* L.) is one of the important cereal crop in Ukraine. The plant uptake index was calculated as the ratio between Cd, Pb, Zn, Cu concentration in spring barley and its available form in soil. The investigation was carried out on sod podzolic sandy loam and chernozem soils. Sod podzolic sandy loam soil occupies one-third of the total area of arable lands in Ukraine, while chernozems more than half of that area[14].

The aim of our investigation has been to assess the toxic tolerance range of spring barley to the high level of impact pollution with Cd, Pb, Cu, and Zn.

EXPERIMENTAL APPROACH

The soils of experimental plots were: sod podzolic sandy loam on layered glacial sands (sod podzolic) and calcareous deep chernozem on loamy loess (cernozem). Sod podzolic soil has the following physic chemical characteristics: pH_{salt} 5.5; organic matter by Turin 0.87%, CEC 6.3 mg eqv/100 g. Chernozem soil has the following: pH_{salt} 6.2, organic matter by Turin 2.89%, CEC 27.1 mg eqv/100 g.

Studied trace elements: Cd, Pb, Zn, and Cu were applied one time in the amount equal to the following concentration in the soils:

Cd: 45, 90, 150, 300 mg kg^{-1} of the soils.
Pb: 300, 450, 900, 1500 mg kg^{-1} of the soils.
Cu: 200, 300, 500 mg kg^{-1} of the soils.
Zn: 900, 1100, 1500 mg kg^{-1} of the soils.

That amount corresponds to the Maximum Allowed Concentration (MAC) in soil adopted in Ukraine [15]. The applied amounts are kept within the limits of 10 to 100 MAC. For copper and zinc, however, the maximum applied concentration was equal to 10 MAC and with higher concentration (Cu – 1000 mg kg^{-1}, and Zn 3000 mg kg^{-1}) all plants died. Therefore, the articles refer to the results from only three levels of the impact pollution of Zn and Cu.

The following metals salts: $Pb(NO_3)_2$, $ZnSO_4 \cdot H_2O$, $CuSO_4 \cdot 7H_2O$, $CdSO_4$ were used for the trace elements application. The investigation was conducted in green house conditions. Plants grew in plastic Mitcherlikh's pots. Soil preparation, pots filling, and trials were carried out in accordance with methodic standards. The metals were added to soil during soil preparation before filling the pots. Then, spring barley germinated seeds were planted into the pots and, in the stage 3 of leaves, the recommended population was established.

Trace element determination in the plants was carried out after wet digestion by mixture of H_2SO_4 and $HClO_4$ (by Ginsburg) [16,17]. The studied elements were extracted by 1 M HCl from the soils. The methods of the HM determination were the thin layer chromatography (TLC). Both methods were widely used in our previous investigation and were officially established in Ukraine [17].

The plant up-take index (*I*) was calculated as [1, 8, 18-20]:

$$I = \frac{C_{plant}}{C_{soil}} \qquad (1)$$

where:

C_{plant} –HM concentration in plant (or a part of plant), mg kg^{-1};
C_{soil} –HM concentration (available form) in 0-20 cm soil layer, $mgkg^{-1}$.

The Table 1 demonstrates the plant uptake index of spring barley (Hordeum vulgare L.) on uncontaminated soils (control).

TABLE 1. SPRING BARLEY UPTAKE INDEXES ON UNCONTAMINATED SOIL

Metal	1 M HCl extracted forms in soil, mg kg^{-1}	Concentration in plant, mg kg^{-1}	Uptake index (I)
Chernozem			
Cd	0.11±0.05	0.006±0.001	0.05
Pb	0.32±0.1	0.022±0.005	0.07
Cu	2.60±0.5	2.860±0.5	1.10
Zn	5.30±0.7	8.480±0.8	1.60
Sod podzolic			
Cd	0.10±0.05	0.005±0.001	0.05
Pb	0.30±0.1	0.015±0.005	0.07
Cu	0.92±0.2	1.200±0.3	1.10
Zn	2.40±0.4	4.320±0.5	1.60

RESULTS AND DISCUSSION

Cadmium

Applied Cd interacts with the soils. Concentrations of available form (extracted with 1.0 M HCl) of the studied metal vary in the studied soils. These results were predictable and discussed in many publications [21-27]. In our case, the ratio of the available form of Cd in sod podzolic soil is above 50% of applied amounts, while for chernozem – it is slightly below. Similarly, the concentration of cadmium in the plant tissue is higher on sod podzolic than in chernozem when the same amount of the contaminant was applied.

Applied amounts of Cd reduced the total weight of the whole plant as well as the height (Table 2).With the increase in cadmium application, the plant height, its total weight per plot reduced at the beginning due to the applied concentration of 45 mg kg^{-1} of the soils. With the pollution increase, plants quantity reduced to 80% of the initial quantity, on the plot with 90 mg kg^{-1} of the applied cadmium on sod podzolic soil and with 150 mg kg^{-1} – on chernozem.

Cadmium pollution impact on concentration of its available form in soil, plant and reduction of spring barley biomassAs soon as the same impact pollution on two studied soils caused different accumulations of cadmium in the plant tissue, we could observe the influence of 8 different concentrations of cadmium in the plants on the plant height and biomass reduction. These two curves obtained on the different soils that were similar to each other on the graph, only show the influence of the cadmium concentration in tissue on plants height (Fig 2). We interpret the influence of cadmium pollution on the plant height with exponential trend line which shows quite a high level of approximation

TABLE 2. THE EFFECTS OF APPLIED CD ON PLANT WEIGHT AND HEIGHT

Applied Cd mg kg^{-1} of soil	1 M HCl extracted forms in soil. mg kg^{-1}	Concentration in plant mg kg^{-1}.	Plant height. cm		Plants weight. g		
			Height. cm	% to control	Mean of the plant weight. g	Plants quantity compared to control %	Plants weight compared to control. %
Sod podzolic							
Control			61.9±0.6	100	31.4±0.5	100	100
45	22.9±2.5	15.6±2.0	50.7±4.9	81.9	25.3±0.5	100	80.7
90	46.4±4.0	29.3±2.5	36.1±3.5	58.7	18.2±0.3	80	57.8
150	77.1±5.6	50±5.0	24.97±2.0	40.6	12.3±0.3	80	39.3
300	153.1±9.6	87.1±7.2	3.2±0.5	5.2	1.4±0.1	70	4.4
Chernozem							
Control			62.0±0.6	100	31.6±0.5	100	100
45	20.8±2.0	13.7±2.0	59.23±5.0	95.54	30.2±0.5	100	94.3
90	41.7±3.6	23.5±2.7	46±4.0	74.2	23.4±0.5	100	73.1
150	68.2±5.5	37.7±3.8	31.12±3.5	50.2	15.8±0.3	80	49.3
300	138.9±9.0	74.8±5.8	11.59±1.5	18.7	5.6±0.1	80	17.5

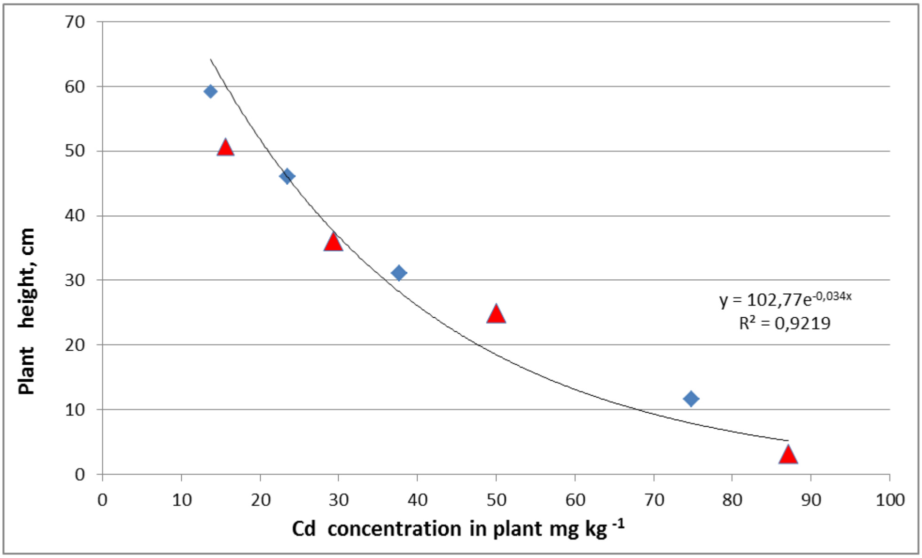

Fig. 2. Influence of cadmium concentration in plant tissue on plant height reduction (*red triangles show cadmium concentration from the plants growing in chernozem soil and blue rhombus from the plants growing on sod podzolic soil*).

That way of interpretation replicates well the toxic range of the Shelford curve of ecological tolerance (Fig. 1). It gives us the possibility to interpret the influence of the impact pollution on: plant height, concentration available form of the metal in soil, and concentration of the metal in plants (Fig. 3) with exponential trend lines.

By using the exponential trend lines we extrapolated the available experimental data to find out the concentration that caused 10% 50% and 90% of the plant weight reduction (Table 2). This value was chosen for its similarity with the ones used in toxicology LD_{10}, LD_{50}, and LD_{90}.

The Plant uptake index for the whole plant in terms of 10%, 50%, and 90% plant height (and biomass) reduction was simulated (Table 3). Given the pollution impact, the uptake index increased significantly in comparison with the control group. However, further increase in contamination caused no significant differences in the uptake indexes. Plant forms constitute the barriers to prevent toxic substance penetration [1, 6, 9, 10, 28, 29-32]. However, the presented data indicates that we can assume that high contaminant pressure destroys that barrier.

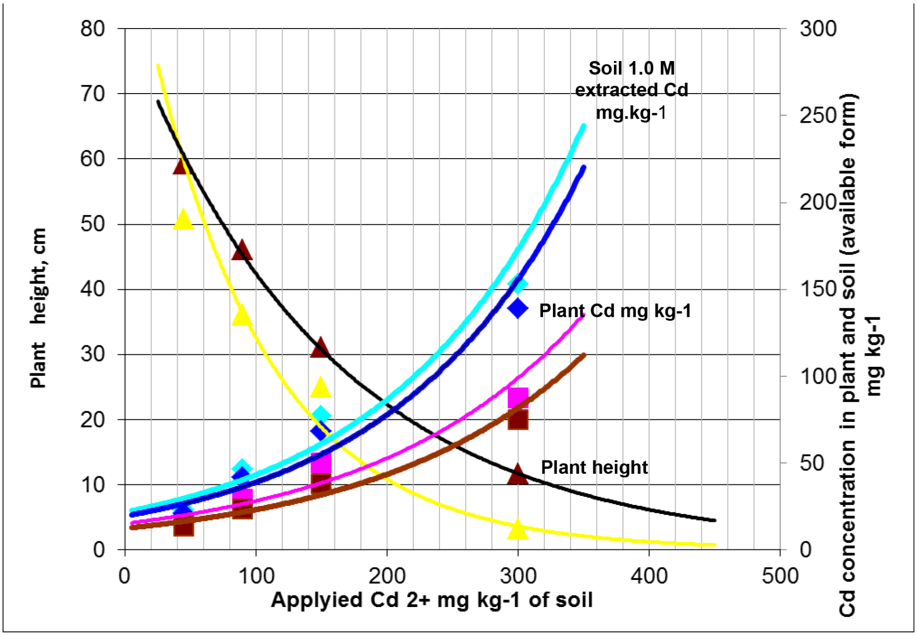

Fig. 3. Relationship between impact pollution of the soils with Cd^{2+} and its concentration of available form in soils, in plants and the plants height.
(*Curves associated with triangles correspond to the impact of applied cadmium on plant height, the yellow one is – on sod podzolic and the brown one – on chernozem; the curves associated with rhombus correspond to the impact of applied cadmium on soil cadmium extracted with 1.0M HCl, the light blue one – on sod podzolic and the dark blue one – on chernozem; and the ones associated with the square correspond to the impact of pollution on plant tissue in terms of cadmium concentration, the rose one – on sod podzolic and the brown one – on chernozem*).

Lead application also had phytotoxic effect on the plants. The Influence of the impact pollution on: plants weight reduction, concentration available forms of lead in soil, and in the plant is shown in the Table 4 and simulated in the Fig. 5. Similarly to cadmium, biomass reduction was observed on the plot with minimal experimental rate of application – 300 mg kg^{-1}. The toxic effect rises when the lead concentration increases, which causes final reduction of the plant height to 4.2 cm as compared with the untreated control group (61.9 cm) on sod podzolic soil. 10% of the plants died at the lead application rate of 900 mg kg^{-1} of the soil and increased to as much as 30% with the application of 1500 mg kg^{-1} of the lead on sod podzolic soil.

TABLE 3. CONCENTRATION OF APPLIED Cd^{2+}, AVAILABLE FORM OF Cd^{2+} IN SOIL, AND Cd^{2+} IN PLANT TISSUE AND PLANT UPTAKE INDEX SIMULATED FOR CONDITION OF THE PLANT BIOMASS REDUCTION OF 10%, 50%, AND 90% LEAD

Plant Biomass reduction.%	Cd			
	Concentration. мgкg^{-1}			Index (total plant)
	Applied Cd	Soil (available form)	Whole plant	
Sod podzolic				
0 (control)		0.10	0.005	0.05
10	56	32.5	21.0	0.646
50	104	45.5	29.5	0.648
90	255	126	75.0	0.595
Chernozem				
0		0.11	0.006	0.05
10	59	29.5	18.0	0.61
50	149	57.0	32.5	0.57
90	396	297	173	0.51

TABLE 4. LEAD POLLUTION IMPACT ON CONCENTRATION OF ITS AVAILABLE FORM IN SOIL, PLANT AND REDUCTION OF SPRING BARLEY BIOMASS

Applied Pb mg kg^{-1}ofsoil	1 M HCl extracted forms in soil. mg kg^{-1}	Concentration in plant. mg kg^{-1}	Plant height. cm		Plants weight. g		
			Height. cм	% to the control	Mean of the plantweight. g	Plants number compared to control %	Phytomas compared to control. %
Sod podzolic							
Control			61.9±0.6	100	31.4±0.5	100	100
300	231.9±18.0	48.6±4.7	53.8±0.4	87.6	27.2±0.5	100	86.50
450.	347.7±20.0	79.9±8.0	48.7±0.4	79.1	24.6±0.4	100	78.30
900	695.1±22.0	105.0±9.7	30.3±1.0	49.2	15.2±0.2	90	48.30
1500	1158.3±20.0	200.0±16.6	4.2±0.1	6.8	1.7±0.1	70	5.50

TABLE 4. CONTINUATION

Chernozem							
Control			62,0±0,6	100	31,6±0,5	100	100
300	212,6±12,0	32,4±0,6	57,6±0,7	92,84	29,4±0,5	100	91,73
450	319,7±15,0	49,5±0,6	61,6±0,6	99,35	31,5±0,6	100	98,41
900	653,8±24,0	102,6±8,2	36,8±0,4	59,30	18,7±0,4	90	58,50
1500	1062,0±25,0	163,5±8,8	6,9±0,3	11,10	3,3±0,1	80	10,20

Lead toxic effect for the plant is more controversial. As in the case with Cd we tried to use the exponential model for interpretation of the experimental data. We observed the influence of 8 different concentrations of cadmium in the plants on the plant height and biomass reduction (Fig. 4). Very high level of approximation gives us the possibility to apply that simulation for farther evaluation of lead phytotoxicity in the figure 5.

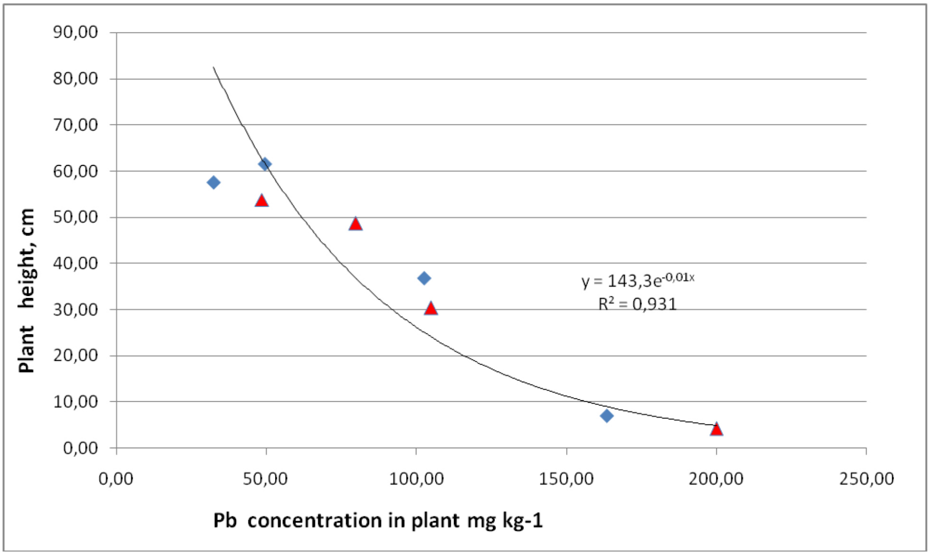

Fig. 4. Influence of lead concentration in plant tissue on plant height reduction (*red triangles show lead concentration from the plants growing in chernozem soil and blue rhombus – from the plants growing on sod podzolic soil*).

Many nonessential and toxic for plant growth trace elements (e.g. Cd or Pb) are absorbed by plants rapidly when they are present in the growing medium [26]. Some investigations showed that nonessential doses of Pb did not inhibit biomass production but stimulated plant growth as well as micronutrients. Lead present in all living organisms and its toxicity and vital necessity for plants is well-proven [29].On the other hand, lead biological role, the mode of action at low concentrations in plants are studied very poorly [30, 31, 32]. We may assume that toxic or stimulation effects also depend on other environmental factors (e.g. the ratio of nutrients in soil solution, organic matter, pH, *etc.*). We also could observe both stimulation and depression effect of lead in our study. The second applied concentration of lead (450 mg kg^{-1}) on chernozem soil caused plant height and weight to increase to the level of the control group.

The pollution impact and concentration in the available form of Pb in soil caused 10%, 50% and 90% of plant height reduction, which was calculated in the Table 5. Here the plant uptake index is also shown.

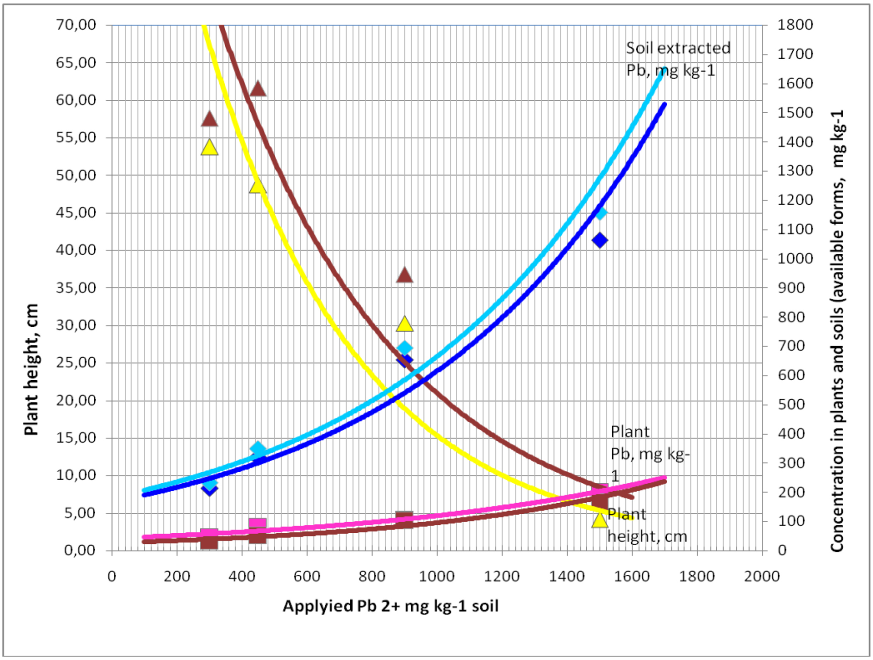

Fig. 5. Relationship between impact pollution of the soils with Pb^{2+} and its concentration of available form in soil, in plant and the plant height.
(*Curves associated with triangles correspond to the impact of applied lead on plant height, the yellow-is on sod podzolic and the brown – on chernozem; curves associated with rhombus correspond to the impact of applied lead on soil lead extracted with 1.0M HCl, the light blue – on sod podzolic and the dark blue – on chernozem; and the one associated with the square correspond to the lead impact pollution on plant tissue lead concentration, the rose one – on sod podzolic and the brown one – on chernozem*).

The lead uptake indexes of barley in contaminated soils are significantly lower than the one of cadmium. The uptake indexes on sod podzolic soils are slightly higher than on chernozem.

Threshold toxic concentration (10% of biomass reduction) of the pollution impact on barley for studied soils significantly varies. For sod podzolic soil, its value is 260 mg kg^{-1}, and for chernozem – it is 460 mg kg^{-1}, while plant concentrations are at the same level – 48 and 49.5 mg kg^{-1}. The same toxic effect (10% of biomass reduction) is caused by very different levels of contamination of the two studied soils. Therefore, the toxic effect of lead contamination on the plant is very much influenced by soil properties.

TABLE 5. CONCENTRATION OF APPLIED Pb^{2+}, AVAILABLE FORM OF Pb^{2+} IN SOIL, AND Pb^{2+} IN PLANT TISSUE AND PLANT UPTAKE INDEX SIMULATED FOR THE PLANT BIOMASS REDUCTION BY 10%, 50%, AND 90% COPPER

Plant Biomass reduction.%	Pb			
	Concentration. мgкg^{-1}			Index (total plant)
	Applied Pb	Soil (available form)	Whole plant	
Sod podzolic				
0		0.30	0.015	0.05
10	260	250	48.0	0.192
50	860	550	105	0.190
90	1460	1190	196	0.164
Chrernozem				
0		0.32	0.022	0.07
10	460	298	49.5	0.166
50	1000	620	104	0.167
75	1550	1246	189	0.151

Copper is an essential trace element for all plants and especially for cereals [6, 9]. The lack of copper on organic soils often limits cereal yield [19, 20]. Nevertheless, the toxic effect of copper for humans and plants is also often reported [1, 4, 6]. The influence of the pollution impact of 2 studied soils on: the concentration of the available form of Cu in soil; the concentration of Cu in plants; and reduction of plants height and weight, is shown in the Table 6.

The toxic effect of copper rises with the copper concentration not as significant as with application of lead and cadmium. The toxic effect of the same concentration of copper on chernozem was less significant than on sod podzolic soil. On the other hand, applied concentrations of copper were relatively lower in comparison to the "safe level" than in the cases with lead and cadmium. As it has been mentioned above, 100% of plant death was observed at the rate equal to 10 MAC (1000 mg kg of soil). Nevertheless, the toxic process development was observed with application of 3 different concentrations and with other metals interpreted with the exponential trade line (Fig. 6).

TABLE 6. COPPER POLLUTION IMPACT ON CONCENTRATION OF ITS AVAILABLE FORM IN SOIL, IN PLANT, AND REDUCTION OF SPRING BARLEY HEIGHT AND WEIGHT

Applied Cu mg kg-1ofsoil	1 M HCl extracted forms in soil. mg kg^{-1}	Concentration in plant. mg kg^{-1}	Plant height. cm		Plants weight. g		
			Height. cм	% tocontrol	Mean of the plant weight. g	Plants number compared tocontrol %	Phytomas compared tocontrol. %
Sod podzolic							
Control			61.9±0.6	100	31.4±0.3	100	100
200	67.2±4.5	35.0±3.3	55.8±0.5	90.70	28.2±0.3	100	89.70
300	102.9±9.7	59.0±5.9	49.9±0.5	81.20	25.1±0.2	100	80.00
500	173.8±10.0	93.4±7.8	11.3±0.1	18.40	5.5±0.1	70	17.60
Chernozem							
			62.0±0.6	100	31.6±0.3	100	100
200	59.5±5.0	28.1±2.0	60.3±0.5	97.20	30.8±0.3	100	96.10
300	87.6±7.5	44.6±3.8	56.8±0.5	91.60	28.9±0.2	100	90.30
500	144.3±10.0	64.9±6.0	30.4±0.3	49.02	15.4±0.2	70	48.10

Interpretation of the influence of applied amounts of cooper on: plant biomass reduction, concentration of the available form of copper in soil, and concentration of copper in plant tissue (Fig. 6) with exponential trend lines is supplemented with calculation of these values for 10% 50% and 90% of biomass reduction (Table 7). The copper uptake index on different levels of copper contamination is also demonstrated in the Table 7.

Copper uptake indexes in contaminated soils are higher on both soils than uptake indexes of lead and a little lower than the one of cadmium. On the other hand, in the uncontaminated soil (the control group), the copper uptake index is above 1. This is the main difference of copper with lead and cadmium behaviour. We may assume that plants form barriers to copper penetration through roots when the soil available concentration of Cu^{2+} exceeds the “safe level” for the plant. The copper uptake from sod podzolic soil is more intensive than from chernozem soil. Soil with higher organic matter (chernozem) has better binding capacity [1, 3, 6, 23] and, therefore, the lower uptake index than sod podzolic soil as it is the case with cadmium.

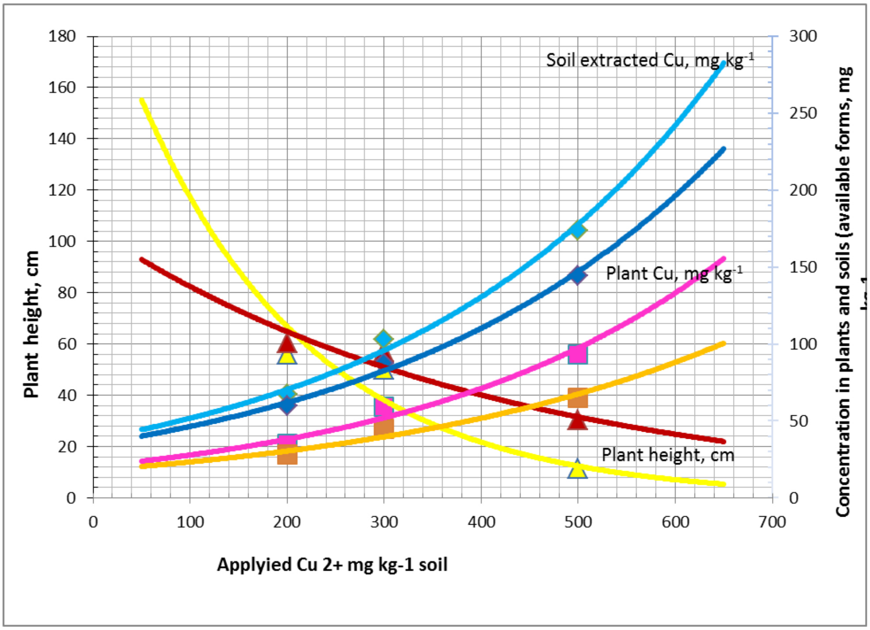

Fig. 6. Relationship between the pollution impact of the soils with Cu^{2+} and its concentration of available form in soil, in plant and the plant height.

(Curves associated with triangles correspond to the impact of applied copper on plant height, the yellow one is on sod podzolic and the brown one is on chernozem; curves associated with rhombus correspond to the impact of applied copper on soil copper extracted with 1.0M HCl, the light blue one – on sod podzolic and the dark blue one – on chernozem; and the ones associated with the square correspond to the pollution impact of copper on plant tissue copper concentration, the rose one – on sod podzolic and the brown one – on chernozem).

Zinc is another essential trace element for plants in our study. As it is the case with copper, the extremely high concentration of Zn – at the level higher than 10 MAC (3000 mg kg soil) caused 100% plants death. The influence of different levels of the pollution impact on: concentration available forms of zinc in soil, concentration in plants tissue, plants height, and biomass is shown in the Table 8. Zinc application had the toxic effect on the plant beginning with the first concentration on both soils. Application of 1500 mg kg^{-1} of zinc caused reduction of the height of the plant by 12.3% of the height in the control group on sod podzolic soil and by 31.3% – on chernozem. As for the other studied metals the ratio of height and weight reduction caused by the pollution impact was similar.

TABLE 7. CONCENTRATION OF APPLIED Cu^{2+}, AVAILABLE FORM OF Cu^{2+} IN SOIL, IN PLANT TISSUE AND PLANT UPTAKE INDEX FOR THE PLANT BIOMASS REDUCTION BY 10%, 50%, AND 90%

Plant Biomass reduction.%	Cu			
	Concentration. мgкg^{-1}			Index (total plant)
	Applied Cu	Soil (available form)	Whole plant	
Sod podzolic				
		0.92	1.2	1.300
10	235	46	25	0.543
50	340	64	36	0.563
90	640	164	90	0.548
Chernozem				
		2.6	2.9	1.100
10	260	44	22	0.500
50	500	88	40	0.455
90	1200	400	180	0.450

TABLE 8. ZINC POLLUTION IMPACT ON CONCENTRATION OF ITS AVAILABLE FORM IN SOIL, PLANT AND REDUCTION OF SPRING BARLEY BIOMASS

Applied Zn mg kg^{-1}ofsoil	1 M HCl extracted forms in soil. mg kg^{-1}	Concentration in Plant. mg kg^{-1}	Plant height. cm		Plants weight. g		
			Height. cм	% tocontrol	Mean of the plant weight. g	Plants number compared to control %	Phytomascomparedtocontrol. %
Sod podzolic							
Control			61.9±0.6	100	31.4±0.3	100	100
900	427.4±24.0	120.0±10.0	53.1±0.5	86.30	26.8±0.3	100	85.40
1100	550.3±25.0	162.0±11.0	49.4±0.5	80.30	24.8±0.2	100	79.10
1500	743.0±31.0	214.8±17.0	7.6±0.6	12.30	3.5±0.1	70	11.20

TABLE 8. CONTINUATION

Chernozem							
			62,0±0,6	100	31,6±0,3	100	100
900	382,3±25,8	100,5±9,8	57,9±0,5	93,40	29,5±0,3	100	92,20
1100	483,5±35,0	147,8±10,6	54,3±0,4	87,50	27,7±0,3	100	86,70
1500	656,5±56,0	175,8±12,0	19,4±0,2	31,32	9,8±0,1	70	30,50

As for other studied metals we interpreted the influence of the pollution impact on: biomass reduction, concentration available form of zinc in soil, and zinc concentration in plant tissue with the exponential trend line (Fig.7). As for other metals, the pollution concentration impact, concentration available form in soil, and concentration of zinc in plant that caused 90%, 50%, and 10% of biomass reduction were calculated (Table 9).

Zinc uptake indexes were lower than the one of copper and very similar for both soils. Likewise with copper and contrary to cadmium and lead, the plant uptake index of uncontaminated soil is above 1. The mean zinc uptake index on sod podzolic soil is slightly higher than on chernozem.

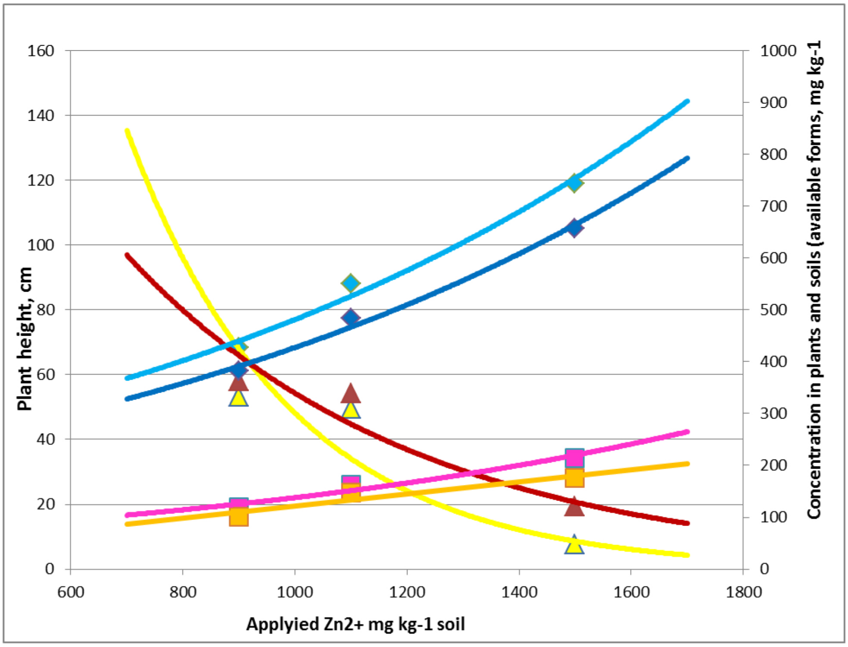

Fig. 7. Relationship between the pollution impact of the soils with Zn^{2+} and its concentration of available form in soil, in plant and the plant height.

(*Curves associated with triangles correspond to the impact of applied zinc on plant height,the yellow one-is on sod podzolic and the brown one on chernozem; curves associated with rhombus* *correspond to the impact of applied zinc on soil zinc extracted with 1.0M HCl, the light blue one – on sod podzolic and the dark blue one – on chernozem; and the ones associated with the square correspond to the pollution impact with zinc on plant tissue zinc concentration, the rose one – on sod podzolic and the brown one – on chernozem*).

TABLE 9. CONCENTRATION OF APPLIED Zn^{2+}, AVAILABLE FORM OF Zn^{2+} IN SOIL, Zn^{2+} IN PLANT TISSUE AND THE PLANT UPTAKE INDEX FOR THE PLANT WEIGHT REDUCTION BY 10%, 50%, AND 90%

Plant Biomass reduction.%	Zn			
	Concentration. мg кg^{-1}			Index (total plant)
	Applied Zn	Soil (available form)	Whole plant	
Sod podzolic				
		2.4	4.32	1.800
10	960	470.0	127	0.270
50	1130	550.0	180	0.327
90	1620	825.0	250	0.303
Chernozem				
		5.3	8.48	1.600
10	1000	420.0	118	0.280
50	1290	550.0	160	0.290
90	2120	1140.0	265	0.232

CONCLUSIONS

1. Evaluation of the phytotoxic process of trace elements (Cd, Pb, Cu, and Zn) for plants of spring barley (*Hordeum vulgare* L.) on two different soils gives us the possibility to demonstrate dynamics of the toxic process. The dynamics meets with the toxic part of the Shelford curve. "Milestones' of the toxic process in terms of 10% 50% and 90% of plants height (and weight) were simulated. That may also be named as toxic-tolerance diapason of spring barley plant to the contamination impact.

2. The toxic-tolerance diapasons of spring barley to sod podzolic sandy loam soil contamination with each metal were (available form in soil, mg kg^{-1}): Cd 32.5 – 126,0; Cu 46.0 – 164; Zn 470 – 825; Pb 250 – 1190. The toxic-tolerance diapasons of spring barley to calcareous deep chernozem on loamy loess contamination with each metal were (available form in soil, mg kg^{-1}): Cd 29.5-297; Cu 44.0 – 400.0; Zn 420 – 1140; Pb 298 – 1246.

3. Heavy metals concentrations in the whole plant that caused biomass reduction (10, 50, 90%) were calculated. For each metal these concentrations in

the plant (mg kg^{-1} dry matter) were: Cd (21.0; 29.5; 75.0); Cu (25,0; 36,0; 90,0); Zn (127; 180; 250); Pb (48.0; 105; 196) for plants growing on sod podzolic soil. Similarly, for plants growing on chernozem for each metal these concentrations in plant (mg kg^{-1} dry matter) were: Cd (18.0; 32.5; 173); Cu (22.0; 40.0; 180); Zn (118; 160; 265); Pb (49.5; 104; 189). The contaminant concentrations in plants caused 10% 50%, and 90% biomass reduction and were very similar on both soils.

4. The plant uptake index of the studied contaminants in terms of the pollution impact for Cd and Pb was more than 100 times higher than for the uncontaminated control group. On the other hand, "essential" elements – Cu and Zn had the higher uptake index on uncontaminated soil than in terms of metals application. Plant uptake indexes were: Cd – 0.595-0.646; Pb – 0.164-0.192; Zn–0.270-0.327; Cu – 0.543-0.563 in terms of the pollution impact of sod podzolic soil while on chernozem soil plant uptake indexes were: Cd-0.510-0.610; Pb-0.151-0.167; Zn – 0.232-0.290; Cu – 0.450-0.500. The results show that the toxic process in natural conditions is regulated by both soil and plants interaction with applied trace elements.

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POBIERANIE METALI (Cd, Pb, Zn I Cu) PRZEZ JĘCZMIEŃ JARY UPRAWIANY NA GLEBACH ZANIECZYSZCZONYCH

Celem pracy było określenie wpływu zanieczyszczenia gleb piaszczysto-gliniastych bielicowych i czarnoziemów przez matale ciężkie (Cd, Pb, Zn, Cu) na biakumulację tych pierwiastków w jęczmieniu jarym (Hordeum vulgare L.). Podwyższone stężenie metali ciężkich spowodowało spadek plonu biomasy (od 10 do 90%). Stwierdzono, że im wyższe stężenie pierwiastków w glebie tym reakcja negatywna roślin była większa, aż do zamierania roślin. Wyliczono wskaźniki akumulacji dla każdego z pierwiastków metali. Ocena dynamiki procesu zanieczyszczenia gleb przez metale ciężkie (na podstawie wskaźników akumulacji) daje możliwość stymulowania stężenia tych pierwiastków w glebie.