DOI: 10.2428/ecea.2012.19(07)069 ECOL CHEM ENG A. 2012;19(7):699-706

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ASSESSMENT OF ZINC CONTENT AND MOBILITY IN MAIZE

OCENA ZAWARTOŚCI I MOBLINOŚCI CYNKU W KUKURYDZY

Abstract: The research aimed to assess the content and mobility of zinc in maize cultivated in soils polluted with this element. The indicators of the assessment were: zinc content in maize, zinc concentration index, zinc bioaccumulation and translocation index. A two-year pot experiment was conducted parallel on soils: light and heavy one. Four levels of zinc were applied in the experiment: Zn_0 – 0 mg (control), Zn_1 – 50 mg, Zn_2 – 250 mg and Zn_3 – 750 mg · kg^{-1} soil d.m. Zinc content in the aerial parts and roots was determined after dry mineralization and dissolving the ashes in HNO_3 using atomic emission spectrometry in inductively coupled argon plasma (ICP-AES). Soil contamination with zinc significantly affected an increase in this metal contents in the aboveground and underground maize biomass. The aboveground biomass obtained on the light soil contained 2-fold (Zn_1), 5-fold (Zn_2) and 25-fold (Zn_3) bigger amounts of zinc in comparison with the treatment without zinc supplement. On the other hand, on the heavy soil the dependencies were respectively 2-fold (Zn_1), 7-fold (Zn_2) and 19-fold (Zn_3). Bigger zinc content was assessed in roots than in the aerial parts and the dependence was confirmed by low values of the translocation coefficient (TC). Greater phyto-availability and phytotoxicity of zinc was demonstrated in the light soil than in the heavy soil. The relationship was confirmed by a better zinc solubility determined by 1 mol HCl · dm^{-3} in the light soil but also by higher values of zinc bioaccumulation coefficients in this soil.

Keywords: maiz, zinc, concentartion index, bioaccumulation and translocation coefficient

Zinc, due to its many physiological functions in plants is considered as their crucial nutrient [1]. However, since it is quite common in the environment, being also a component of many compounds emitted to the natural environment and present in waste substances used in agriculture, it may accumulate in soil. Excessively high zinc concentration in soils is harmful to plants because this metal easily accumulates in vegetative and generative plant parts, which in consequence may lead to their growth inhibition, decline in yields and worsening of their quality [2–5]. This phenomenon is commonly known as phytotoxicity [6, 7]. Generally plants reveal considerable tolerance to elevated zinc content in soil whereas the extent of zinc tolerance depends in the first place on physicochemical properties of soil. Bioavailability and mobility of zinc are determined by the following soil factors: soil pH, granulometric composition, organic

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matter content, the from in which zinc occurs in soil and its solubility [8–10]. The research aimed to assess the content and mobility of zinc in maize cultivated in soils polluted with this element.

Material and methods

A two-year pot experiment was conducted parallel on soils: light and heavy one. The light soil with granulometric composition of weakly loamy sand was characterized by slightly acid reaction, whereas the heavy soil with granulometric composition of loamy silt had acid pH. Total zinc content in the light soil was 62 mg and in the heavy soil 158.35 mg $\cdot$ kg^{-1}. Zinc soluble in 1 mol HCl $\cdot$ dm^{-3} constituted 36 % of its total content in the light soil and 16 % in the heavy one. Four levels of zinc were applied in the experiment: Zn_0 – 0 mg (control), Zn_1 – 50 mg, Zn_2 – 250 mg and Zn_3 – 750 mg $\cdot$ kg^{-1} soil d.m. The same mineral fertilization: 0.225 gN, 0.14 gP and 0.275 gK $\cdot$ kg^{-1} soil d.m. was applied on all experimental treatments. Mineral salts as zinc sulphate(VI), ammonium nitrate(V), potassium dihydrophosphate(V) and potassium chloride were supplied prior to the plant sowing. The test plant was maize (*Zea mays*), "Bora" c.v. The plants were harvested at the 7–9 leaves phase, after 40 days of vegetation. The analysis of the plant material chemical composition was conducted to assess the chemical effects of the soil contamination with zinc. The indicators of the assessment were: zinc content in maize, zinc concentration index, zinc bioaccumulation and translocation index. Zinc content in the aerial parts and roots was determined after dry mineralization and dissolving the ashes in HNO_3 using *atomic emission spectrometry in inductively coupled argon plasma* (ICP-AES) on JY 238 ULTRACE apparatus (Jobin Yvon). Obtained results were elaborated statistically by means of one-way ANOVA and Tukey test. The test was applied when no equality between means was revealed. ANOVA was conducted at the significance level $\alpha = 0.01$.

Results

Zinc concentrations in maize were diversified depending on zinc dose, kinds of soil and analyzed part of test plant (Table 1).

Table 1

Content of zinc in aboveground biomass and roots of maize

Treatment		Aboveground biomass		Roots	
		[mg $\cdot$ kg^{-1} d.m.]			
		Light soil	Heavy soil	Light soil	Heavy soil
Zn_0	0 mg*	51.96^{a*}	33.63^{a}	137.54^{a}	91.38^{a}
Zn_1	50 mg	94.97^{a}	64.10^{a}	288.31^{b}	155.75^{b}
Zn_2	250 mg	256.29^{b}	220.56^{b}	999.77^{c}	751.07^{c}
Zn_3	750 mg	1300.75^{c}	624.40^{c}	2493.33^{d}	1743.94^{d}
LSD $_{0.01}$		*75.15*	*32.99*	*50.05*	*65.95*

* Homogenous groups according to Tukey test, $\alpha < 0{,}01$, ** mg $\cdot$ kg^{-1} d.m.

Soil pollution with zinc significantly affected increase in this metal content in aboveground biomass and roots (Table 1). The aerial biomass obtained on the light soil contained 2-fold (Zn_1), 5-fold (Zn_2) and 25-fold (Zn_3) higher amounts of zinc in comparison with the treatment without zinc supplement. On the other hand on the heavy soil the dependencies were 2 (Zn_1), 7 (Zn_2) and 19 (Zn_3). Irrespectively of the kind of soil, the underground biomass contained respectively 2-fold (Zn_1), 8-fold (Zn_2) and 19-fold (Zn_3) bigger amounts of this metal in comparison with the roots from the control. Higher zinc contents were assessed in the roots than in the aboveground parts. Maize roots contained between 2 and 4 times more of this element in the light soil and between 2 and 3 times more in the heavy soil in comparison with the aboveground biomass. Higher zinc concentrations in the analyzed maize parts, respectively from 16 to 108 % (aerial parts) and from 33 to 85 % (roots) were determined in the light than in the heavy soil. Zinc concentration index (C_i) was computed in the investigations (Fig. 1).

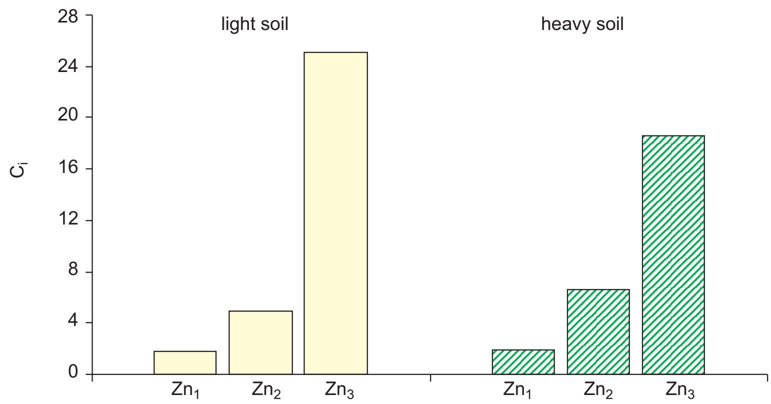

Fig. 1. Zinc concentration index (C_i) in maize

Concentration index (C_i) is an indicator of toxic elements bioaccumulation in plants [3, 10]. The parameter was calculated as a ratio of zinc content in a contaminated plant to this element content in the control plant. The value of zinc concentration index was diversified and fluctuated from 1.83 to 25.03 in the light soil and from 1.91 to 18.57 in heavy soil (Fig. 1). On treatments with Zn_1 (50 g) and Zn_2 (250 mg $\cdot$ kg^{-1} d.m.) the index assumed on average 14 % higher value on heavy soil than on the light one. Only on the treatment with 750 mgZn $\cdot$ kg^{-1} d.m. an opposite relationship was observed. Both on the light and heavy soil value of concentration index was increasing under the influence of increasing zinc doses. Growing C_i values evidence considerable zinc accumulation in maize, posing a serious hazard for animals and humans as potential plant consumers.

Bioaccumulation and translocation coefficients were computed (Table 2) to assess the extent and direction of zinc mobility in maize. Value of bioaccumulation coefficient reflected plant ability to absorb zinc from soil and informs about this metal translocation from the soil solution to the plant aboveground parts [11–14]. The index is a ratio of the metal content in plant to its amount in soil. On the other hand, *translocation coefficient* (TC) was used to assess zinc mobility in maize [14]. This parameter was calculated as a ratio of zinc content in plant aboveground parts to its content in roots. Higher zinc accumulation in roots, in comparison with its aerial parts has been confirmed by low values of its translocation coefficients (TC) (Table 2). Moreover, with growing pollution of the light soil to 250 mgZn · kg^{-1} d.m., maize accumulated increasingly more zinc in roots whereas TC values were decreasing. On the other hand, on the treatment with 750 mgZn · kg^{-1} d.m. this metal to a greater extent moved from roots to the aboveground parts, as it has been evidenced by higher value of translocation coefficient. A different dependence was observed in the heavy soil, where the lowest dose of zinc (50 mgZn · kg^{-1} d.m.) caused a greater mobility of this metal from roots to the aerial parts in comparison with the control and treatments with higher level of zinc pollution (Table 2). At the doses of 250 and 750 mgZn · kg^{-1} d.m. of heavy soil, maize roots accumulated zinc to a greater extent than the aboveground parts, which has been confirmed by lower TC value in comparison with the control (Table 2).

Table 2

Translocation and bioaccumulation coefficient

Treatment		Translocation coefficient		Bioaccumulation coefficient			
		Aboveground biomas / Root		Root / Soil		Aboveground biomas / Soil	
		Light soil	Heavy soil	Light soil	Heavy soil	Light soil	Heavy soil
Zn_0	0 mg*	0.38	0.37	1.96	0.63	0.74	0.23
Zn_1	50 mg	0.33	0.41	2.05	0.86	0.68	0.35
Zn_2	250 mg	0.26	0.30	2.95	2.01	0.76	0.59
Zn_3	750 mg	0.52	0.35	3.37	2.10	1.76	0.75

* mg · kg^{-1} soil.

The analysis of bioaccumulation coefficient value revealed that increasing doses of zinc generally caused an increase in *bioaccumulation coefficient* (BC) value in relation to the treatment without zinc supplement (Table 2). Both in the light and heavy soil higher zinc content occurred in roots and smaller in the aboveground parts. Assessment of zinc bioaccumulation degree demonstrated its intensive accumulation in roots (BC 1–10) and medium (BC 0.1–1) in the aerial parts. Moreover, it was shown that in the light soil this parameter assumed from over 1 to 3-fold higher values in comparison with the heavy soil (Table 2). Obtained results evidence a better ability of zinc passing from the light soil to various maize parts. On the other hand, lower values of bioaccumulation coefficient (BC) on heavy soil testify a slightly poorer uptake of the analyzed element by plants in this soil. It was also corroborated by poorer zinc solubility in 1 mol HCl · dm^{-3} in heavy than in light soil, on average 57 % of its total content (in heavy soil) and 80 % (in light soil) (Fig. 2). In the light soil soluble zinc constituted between 66 and 98 %, whereas in the heavy soil between 45 and 75 % of its total content. Observed increase in zinc solubility in soils with increasing zinc dose

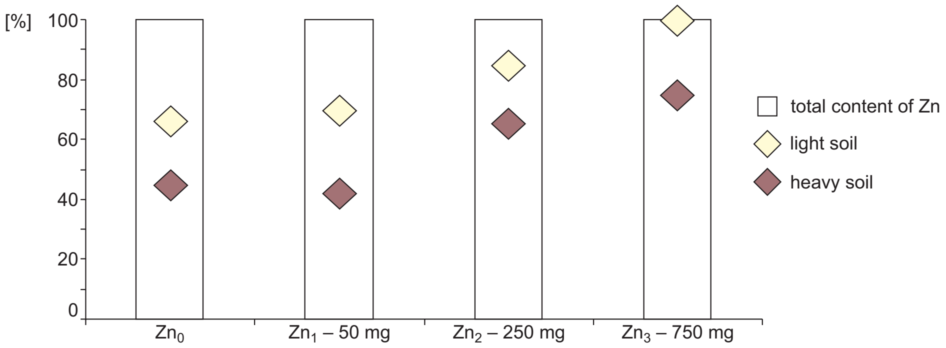

Fig. 2. The percentage soluble forms of zinc in the total content of this metal in the light and heavy soil

indicates a strict dependence between zinc content in maize and the content of its soluble forms in soil (Figs. 3 and 4), but also the fact stated by other authors that zinc uptake by plants in relation to its content in the soil solution is the dependence most approximate to the straight-line one, as compared with other metals [3]. Obtained results confirm high, significant values of the correlation coefficient between zinc content in maize and this metal concentrations in soils. In the light soil values of the correlation coefficient between zinc concentrations in the aboveground parts and roots and its content in soil were respectively 0.98 and 0.97 at $p < 0.01$, whereas in the heavy soil 0.87 and 0.84.

A very important factor at high zinc concentrations in soil is the chemical effect, *ie* zinc accumulation in the tissues of cultivated plant. In the Authors' own investigations the chemical effect was determined as an index of concentration informing about an increase in zinc content in plants in the light and heavy soil at growing doses of this metal in relation to the control. Moreover, it was demonstrated that zinc content in maize corresponded with the content of its soluble forms in soils and with its growing

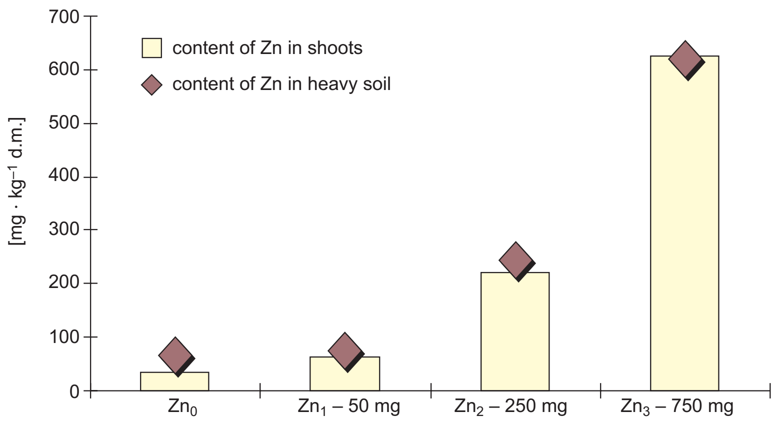

Fig. 3. Relation between content of zinc in shoots and content of zinc in heavy soil

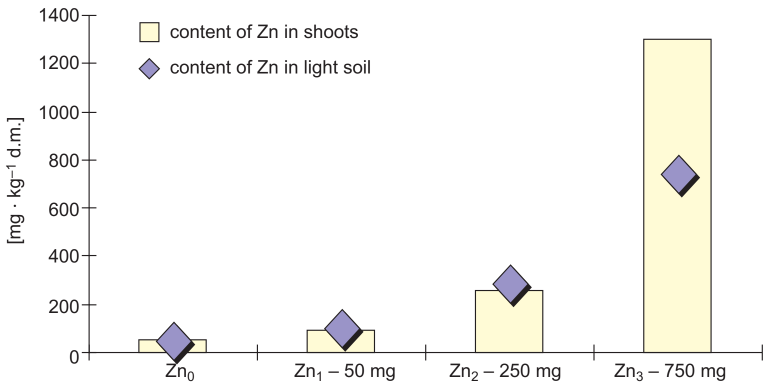

Fig. 4. Relation between content of zinc in shoots and content of zinc in light soil

concentrations in soil zinc accumulation in plants was increasing, too. The dependence has been confirmed also by high and significant correlation coefficients between zinc concentrations in maize and the content of its forms soluble in 1 mol HCl $\cdot$ dm^{-3} in soils. Research conducted by other authors [10, 15] showed similar dependencies by extracting zinc with 1 mol HCl $\cdot$ dm^{-3}. On the other hand, while analyzing the effect of soil kind on zinc content in maize it was found that its parts from light soil were characterized by higher concentrations of this element. Similar dependencies on light soils as compared with heavy soils were revealed in the research of Korzeniowska and Gembarzewski [16]. Investigations conducted by Spiak [3] demonstrated also that values of zinc bioaccumulation coefficients are growing with increasing zinc doses, whereas they diminish with growing soil heaviness, which testifies much smaller potential of zinc uptake from heavy soils than from medium or light ones. Results obtained in the presented experiment confirm this dependence because values of bioaccumulation coefficients were on average over twice higher in light than in heavy soil. Moreover, poorer zinc availability in the heavy than light soil was revealed. The content of zinc soluble in 1 mol HCl $\cdot$ dm^{-3} in heavy soil was on average 57 % of its total content and 80 % in the light soil. Smaller bioavailability of zinc in heavy soil has been also confirmed by lower values of linear correlation coefficients between zinc concentrations in this soil and this element content in the aerial parts and roots as compared with the light soil. Various authors differently present data concerning individual plants sensitivity to zinc stress connected with its excess in the substratum. Causes of diversified plant response to over the norm zinc contents in soils should be explained by different way of absorption and translocation of this element from roots to the aboveground parts. Dicotyledonous plants move big amounts of zinc from roots to the aboveground parts, whereas the unicotyledonous accumulate considerable quantities of zinc in roots [4, 5, 10, 17]. Moreover, greater sensitivity of the dicotyledonous (pea, sunflower, serradella, mustard or buckwheat) to zinc stress results from translocation of big amounts of zinc from roots to the aboveground parts already at the earliest development stages. Das et al [17] and Huicong et al [18] reported that plant ability to heavy metal accumulation is connected with morphological structure of roots. It was found that plants with numerous and thin roots accumulate greater amounts of metals than plants with several thick roots [18]. Maize is characterized by a beam root system, so it may accumulate bigger quantities of heavy metals in roots. Beside specific differences concerning sensitivity to zinc, its distribution in the individual plant parts is diversified whereas the appropriate data are not unanimous. Numerous investigations revealed that zinc is primarily accumulated in roots [17, 20, 21]. Moreover, plants little sensitive to high zinc concentrations defend themselves against contamination by accumulating this element in large amounts in vacuoles of their root cells [22]. Other research demonstrated that zinc in plant aboveground parts cumulates almost in the same way as in their roots [23]. Kabata-Pendias [24] and Spiak et al [10] report that vegetative plant parts are characterized by higher zinc contents than generative ones. On the other hand, Terelak and Lipinski [25] revealed that zinc concentrations in cereal grain are twice higher than in the straw. Also Piotrowska et al [11] stated that young, physiologically active leaves contain considerably greater quantities of zinc in comparison with old leaves, which is associated with the process of this microelement reutilization. The author also demonstrated that at higher zinc concentrations in soil the excess of this metal is arrested primarily in old leaves and shoots, *ie* plant parts with lower physiological activity. In the presented experiment bigger amounts of zinc were assessed in roots than in the aerial parts. Maize roots in light and heavy soils contained on average 3 times bigger quantities of this metal than the aerial parts. Moreover, higher than in the aboveground parts concentrations of zinc in roots were evidenced by the value of zinc translocation coefficients. Considerable zinc contents in roots in comparison with maize aerial parts were also confirmed by higher values of bioaccumulation coefficients (BC) root/soil than BC aerial parts/soil.

Conclusions

1. Soil contamination with zinc significantly affected an increase in this metal contents in the aboveground and underground maize biomass. The aboveground biomass obtained on the light soil contained 2-fold (Zn_1), 5-fold (Zn_2) and 25-fold (Zn_3) bigger amounts of zinc in comparison with the treatment without zinc supplement. On the other hand, on the heavy soil the dependencies were respectively 2-fold (Zn_1), 7-fold (Zn_2) and 19-fold (Zn_3).

2. Bigger zinc content was assessed in roots than in the aerial parts and the dependence was confirmed by low values of the translocation coefficient (TC).

3. Greater phytoavailability and phytotoxicity of zinc was demonstrated in the light soil than in the heavy soil. The relationship was confirmed by a better zinc solubility determined by 1 mol HCl $\cdot$ dm^{-3} in the light soil but also by higher values of zinc bioaccumulation coefficients in this soil.

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OCENA ZAWARTOŚCI I MOBLINOŚCI CYNKU W KUKURYDZY

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Abstrakt: Celem badań była ocena zawartości i mobilności cynku w kukurydzy na glebach zanieczyszczonych tym pierwiastkiem. Jako wskaźniki tej oceny zastosowano: zawartość cynku w kukurydzy, indeks koncentracji cynku, współczynnik bioakumulacji i translokacji cynku. Dwuletnie doświadczenie wazonowe przeprowadzono równolegle na dwóch glebach glebie lekkiej i ciężkiej. W doświadczeniu zastosowano cztery poziomy cynku: Zn_0 – 0 mg (obiekt kontrolny), Zn_1 – 50 mg, Zn_2 – 250 mg, Zn_3 – 750 mg · kg^{-1} s.m. gleby. Zawartość cynku w częściach nadziemnych i korzeniach oznaczono po suchej mineralizacji i roztworzeniu popiołu w HNO_3 (1:3) metodą atomowej spektrometrii emisyjnej ze wzbudzeniem w indukcyjnie sprzężonej plazmie argonowej (ISP-AES). Zanieczyszczenie gleb cynkiem wpłynęło znacznie na zwiększenie zawartości tego metalu w biomasie nadziemnej i podziemnej kukurydzy. Uzyskana biomasa nadziemna na glebie lekkiej zawierała 2 (Zn_1), 5 (Zn_2) i 25 (Zn_3)-krotnie więcej cynku w porównaniu do obiektu bez dodatku cynku. Z kolei na glebie ciężkiej zależności te wyniosły odpowiednio 2 (Zn_1), 7 (Zn_2) i 19 (Zn_3). Większą zawartość cynku stwierdzono w korzeniach niż w częściach nadziemnych. Zależność tą potwierdzają niskie wartości współczynnika translokacji WT. Większą fitodostępność i fitotoksyczność cynku wykazano w warunkach gleby lekkiej niż ciężkiej. Zależność tą potwierdza większa rozpuszczalność cynku oznaczona 1 mol HCl · dm^{-3} w glebie lekkiej, a także wyższe wartości współczynników bioakumulacji cynku w warunkach tej gleby.

Słowa kluczowe: cynk, kukurydza, indeks koncentracji, współczynnik bioakumulacji i translokacji