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STUDY OF THE INFLUENCE OF Zn CONCENTRATION ON THE ABSORPTION AND TRANSPORT OF Fe IN MAIZE BY AAS AND EDXRF ANALYSIS TECHNIQUES

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Abstract. Zinc is an important microelement for maize (Zea Mays), but its excess in soil can produce various changes within that culture. One of the major problems caused by Zn would be antagonism with Fe, thereby worsening the penetration of Fe ions in various structures. With increasing zinc concentration in soil, iron and zinc distributional changes are observed. By translocation factor (TF) and bio-concentration factor (BCF) determinations (using Atomic Absorption Spectrometry-AAS and Energy Dispersive X-Ray Fluorescence-EDXRF technique) and statistical calculation have been observed affected structures and the migration mechanism of Zn and Fe ions in maize under Zn stress.

Key words: Zea Mays, Zn stress, Zn-Fe antagonism, Zn toxicity, EDXRF, AAS.

1. INTRODUCTION

It is well known that zinc is an important micronutrient for plants [1]; its deficit can cause interveinal necrosis [2]. However, high concentration of this

heavy metal in soil can be toxic for plants [3]. Soil pollution with Zn is determined by various factors, such as mining or industrial sites, buildings construction, and even environmental corrosion of zinc-passivized surfaces of iron items. Therefore, it is normal that Zn is widespread in the environment as a result of various human activities [4].

Zinc is a very mobile metal in the soil, especially in acid or in oxidizing environments. In the pollution conditions existing nowadays, several factors such as the industrial noises or acid rains can greatly enhance the zinc availability for the plants [5]. It is well known that zinc can enter more readily in the plant cells as compared to other elements, such as Pb, Cr, Cu or Ca owing to its lower affinity to polygalacturonic acid. Polygalacturonic acid is a component of the cellular membranes and provides a partial protection against some heavy metals by complexing them [6, 7].

The zinc level in Zea Mays leaves is considered to range between 25 and 100 mg kg^{-1} [8] or between 20 and 70 mg kg^{-1} [9]. As noted by Shrotri, the maximum photosynthetic activity of this plant is at a concentration of 28 mg kg^{-1} in strain [10].

It was shown also that Zn plays a complex role in plants growth being involved in many biochemical reactions related to different enzymes such as: superoxide dismutase [11], dolichyl-phosphate beta-glucosyltransferase [12], hydroxyacylglutathione hydrolase [13], phosphoglycolate phosphatase [14], β-ureidopropionase [15], porphobilinogen synthase [16] and others. Even though for some biochemical reactions the zinc is the main activator, in some cases it can be replaced by other chemical elements. However, in certain situations (*e.g.* lack of certain micronutrients) the zinc takes the role of activator. For example, in the case of enzyme dolichyl-phosphate beta-glucosyltransferase, it is known that the best activator for this enzyme is Mg. But in conditions of Mg deficiency and excess of zinc, it will be possible that Zn take the activator role of Mg [12].

To additionally illustrate this complex role of Zn, it should be mentioned its influence on the increase or decrease in concentration of other chemical elements acting as micronutrients. So-called antagonistic effects of Zn and other elements, such as Cu or Fe [17, 18] leading to decreased intake of these micronutrients in plants have been reported. Synergistic effects were observed in other cases, such as Zn-Cd [19]. The mentioned antagonism of two micro-nutrients (X-Y) means the phenomenon of inhibition the absorption and transport of a micro-nutrient (*e.g.* X) towards the plat organs when another micro-nutrient is present in excess in soil. Consequently, the synergism is the opposite situation, when increased amounts of a micro-nutrient X lead to increased absorption of another micro-nutrient Y'.

A better understanding of the influence of Zn concentration available in soil on plants growth is important for assessing the beneficial results or the risks for agriculture and further for human health if this plant is subsequently used in foodstuffs industry.

As it was already mentioned above, Zn is essential not only for the plants, but also for animals and humans. However, the zinc excess can produce detrimental effects: thus, 40 mg kg^{-1} is a normal Zn intake for cattle; higher Zn concentrations, in the range of 500–1500 mg kg^{-1} Zn in forages, can lead to serious disorders [20].

Zinc toxicity to humans is observed at levels of 100–300 mg per day, among the most important symptoms being the weakening of the immune system and alteration of blood parameters and functionality, anemia, liver and kidney derangement, diarrhea, red urine [21, 22, 23]. Hence, for the contemporaneous agriculture it is an important challenge to well understand the interaction of heavy metals micronutrients with the plants, as a fundamental element of animal and human food chains, under the actual conditions of complex pollution of soil, air and water due to human activities (nonferric metal industry and agricultural practice).

In this study, we investigated the effect of soil doping with various Zn concentrations on the growth of corn (*Zea Mays*) as well as on the uptake (absorption and transport) of other micronutrients namely Fe from soil. This study is part of a project to assess the environmental impact of heavy metals pollution of soil on agriculture. In this direction, zinc is one of the metals extensively produced and used in various practical applications. On the other hand, the chosen plant for study, *Zea Mays* either is widely cultivated in all regions of Romania, the agricultural lands being often located near mining or industrial sites, closed or still active. Frequently, in the soil of such areas present were detected significant concentrations of zinc and other heavy metals [24].

The approach used in this work was to follow the effect of controlled Zn concentrations in the soil on the absorption and transport of various nutrients from the soil to the plant organs. We are investigated also the stress-related effects of the zinc, namely the growth parameters and the distribution of Fe in the plant.

2. MATERIALS AND METHODS

2.1. PREPARATION OF SOIL SAMPLES

In this work, we used as reference a peat rich soil with the following elemental composition (in mg kg^{-1} soil): 6.514 ± 0.208 (Zn); 861.777 ± 11.065 (Fe) The content of heavy metals in reference soil used is within the admissible limits according to Romanian and foreign regulations [25, 26].

For controlled soil contamination has been used an aqueous solution of $Zn(CH_3COO)_2$ with concentration of 100 mg L^{-1}. All soils were contaminated with adequate amounts of Zn solution. Afterwards, the treated soil was well mixed in order to uniformly disperse the added contaminant.

The following amounts (in mg kg^{-1} soil) of Zn was added to the prepared soil samples in the brackets are indicated the samples designations): 0 (reference); 100 (Zn1); 300 (Zn2); 700 (Zn3).

Finally, the following total zinc concentrations were found by EDXRF analysis of the prepared soil samples (in mg kg^{-1} soil): 6.514 ± 0.208 (reference); 106.479 ± 0.785 (Zn1); 306.207 ± 1.992 (Zn2); 704.859 ± 3.241 (Zn3).

The weighted soil sample (600 g) was placed in a marked pot of 800 mL in volume. Three identic pots were prepared for each soil sample – pristine or contaminated.

2.2. GROWTH OF PLANT SAMPLES

The seeds of the corn (*Zea mays L.* cv. Pioneer) were held for 7 days in a filter paper soaked in distilled water in Petri dishes for germination. Then, the best sprouted seeds were selected for seeding in the already prepared soil samples. Two seeds were placed in each pot.

The growth parameters of the plants were monitored during the first two weeks after the seeding. The samples for chemical analysis were collected after three months of growth.

2.3. ELEMENTAL ANALYSIS

Elemental analysis (of various metals) contained in the studied soil was performed by EDXRF technique (Energy Dispersive X-Ray Fluorescence) [27, 28] by using the ELVA X Light spectrometer. This equipment contains a X-ray tube (air chilled), with a Be window of 140μm aperture and a Rh anode. The applied current is in the range 0–100 μA, adjustable in 0.2 μA steps and the voltage is in the range 4–50 kV, adjustable in 0.1 kV steps. The X-ray detector is a Si-PIN diode, thermoelectrically chilled, with an energy resolution of 180 eV–5.9 keV (^{55}Fe isotope). The maximal beam power is 5 W. For each interested element it was used a standard solution of that element (Cu, Fe, Zn) with a known concentration. The determinations of the soil concentration were made by comparing the EDXRF spectrum of the sample with the addition of a standard solution, with the same sample's spectrum without the addition of the standard solution.

The elemental analyses of the samples taken out from different plant organs (roots, leafs, stems) were performed by Atomic Absorption Spectroscopy (AAS) technique using a GBC EDGE Atomic Absorption Spectrometer Model 908 BT instrument. Before analysis, the plant samples (about 0.2 g) were digested with a mixture of 8 ml of HNO_3 (c = 63%) and 10 ml H_2O_2 (c = 30%) [29]. The resulted solutions were placed in 25 ml flasks and diluted to flask volume with ultrapure water (18.5 MΩ cm).

2.4. DATA ANALYSIS

2.4.1. Statistical analysis

For statistical analysis, it was used IBM SPSS Statistics and Microsoft Excel softwares. It was calculated the correlation between the concentration of Zn Fe, Cu with various parts of the plant as determined by the Pearson correlation index of the two programs. The correlations of Zn, Fe with various parts of the plant were calculated through Pearson correlation of both programs being obtained same results. It has been taken into account only the data that had (a two-tailed probability) < 0.01 or < 0.05. For each correlation $N = 4$.

2.4.2. Translocation factor (TF)

As it was mentioned above, the translocation factor from root to stem ($TF_{St/R}$), to young leaves ($TF_{YL/R}$) and to mature leaves ($TF_{ML/R}$) were calculated using the concentrations of heavy metals analyzed in the respective aerial parts of the plant.

To calculate the translocation factor, we used the formula 2.1 [30, 31]:

$$TF_{AP/R} = C_{AP}/C_R, \tag{2.1}$$

where C_{AP} – metal concentration in plant's aerial part; C_R – metal concentration in plant's root.

2.4.3. Bio-concentration factor (BCF)

The bio-concentration factor, defined as the ratio between the concentration of the metal in a certain tissue of the plant and the concentration of metal from the soil, has been calculated using the formula 2.2 [30, 31]:

$$BCF_{P/S} = C_P/C_S, \tag{2.2}$$

where C_P – metal concentration in plant's part; C_S – metal concentration in soil.

Again, the BCF values were calculated for each analyzed heavy metal in the studied plant parts, namely: $BCF_{R/S}$ is the bio-concentration factor from soil to root, while $BCF_{YL/S}$ and $BCF_{ML/S}$ are the BCFs from soil to young lives and mature lives, respectively.

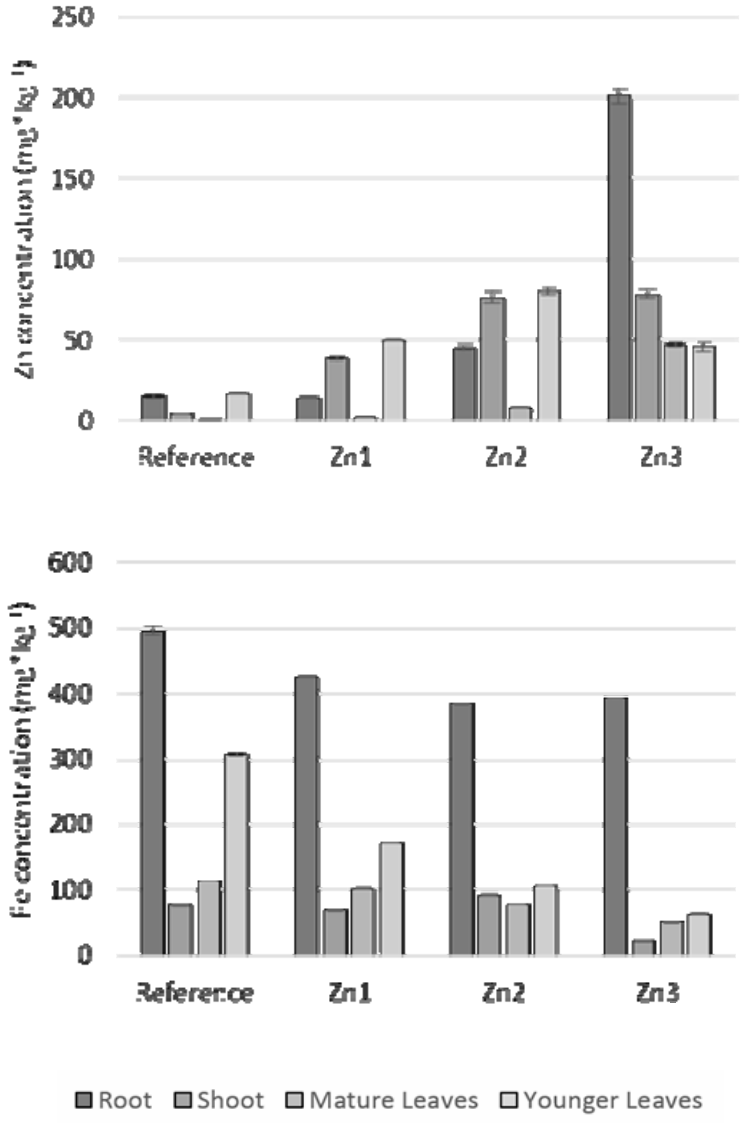

Fig. 1 – Concentration distribution of Zn and Fe (mg kg^{-1}) under Zn stress in maize.

3. RESULTS

According to elemental analysis performed on different parts of the plant and on the soil in which they have grown, the highest concentration of the zinc is recorded in the root (Fig. 1).

Dimensional comparison of the plant samples during the first 12 days after seeding shown that the sample growth in reference soil was the most developed while that cultivated in Zn3-soil had the lowest growth, as it is shown in Fig. 2.

4. DISCUSSIONS

Addition of the Zn in the soil was performed to make a simulation of soil contamination with this element. The levels of soil contaminations with Zn used in this work have the following significance: Zn1 corresponds to the alert threshold, Zn2 is an intermediary level between the alert threshold and the intervention threshold while Zn3 correspond to the intervention threshold [25].

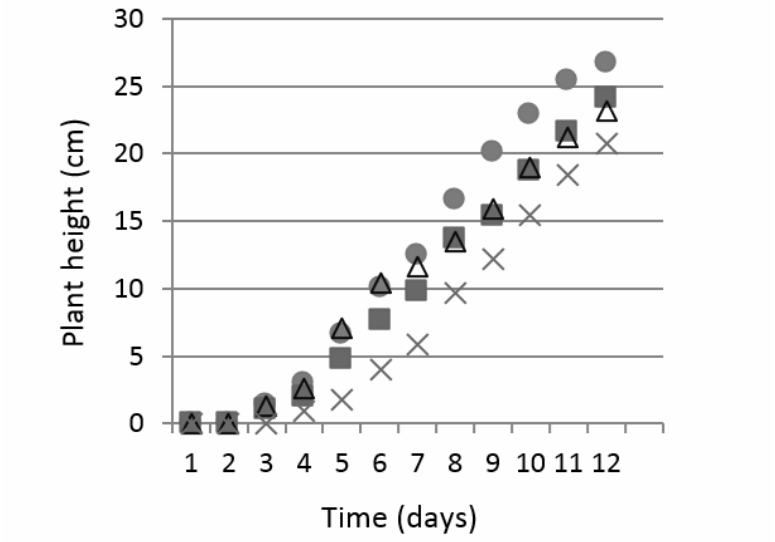

Fig. 2 – Growth evolution of maize samples in the first 12 days of vegetation: (•) reference; (□) Zn1 (100 mg Zn kg^{-1} soil); (Δ) Zn2 (300 mg Zn kg^{-1} soil); (×) Zn3 (700 mg Zn kg^{-1} soil).

In Fig. 1 is represented the Zn and Fe concentration in different parts of plant. It is noted that the zinc excess from soil causes a very interesting distribution of this chemical element at the whole plant level. The distribution of zinc in the whole plant becomes another direction (at low concentrations of zinc in the soil – maximum level of this is in upper parts of the plant, while at high concentrations in the soil zinc is concentrated more in root). According to the graphs, it is understood that in the entire plant, Zn leads to a decrease of Fe concentration.

Table 1

Translocation factor (TF) for Fe and Zn from root to various organs of the plant (St – stem, ML – mature leaves, YL – young leaves) at various levels of zinc in the soil. Bio-concentration factor (BCF) of Zn and Fe from soil to various organs of the plant (R – root; ML – mature leaves, YL – young leaves) for different Zn levels in soil

		Reference	Zn1	Zn2	Zn3
Zn	$TF_{St/R}$	0.305 ± 0.028	2.649 ± 0.157	1.694 ± 0.136	0.391 ± 0.021
	$TF_{ML/R}$	0.016 ± 0.002	0.197 ± 0.024	0.183 ± 0.022	0.234 ± 0.012
	$TF_{YL/R}$	1.121 ± 0.108	3.404 ± 0.146	1.777 ± 0.113	0.227 ± 0.017
	$BCF_{R/S}$	2.344 ± 0.366	0.138 ± 0.014	0.148 ± 0.013	0.285 ± 0.011
	$BCF_{ML/S}$	0.038 ± 0.007	0.027 ± 0.004	0.027 ± 0.004	0.067 ± 0.003
	$BCF_{YL/S}$	2.608 ± 0.356	0.469 ± 0.033	0.263 ± 0.022	0.065 ± 0.004
Fe	$TF_{St/R}$	0.155 ± 0.007	0.163 ± 0.004	0.239 ± 0.005	0.055 ± 0.001
	$TF_{ML/R}$	0.231 ± 0.005	0.241 ± 0.003	0.202 ± 0.003	0.129 ± 0.001
	$TF_{YL/R}$	0.620 ± 0.014	0.403 ± 0.003	0.276 ± 0.003	0.161 ± 0.001
	$BCF_{R/S}$	0.575 ± 0.015	0.493 ± 0.007	0.446 ± 0.008	0.455 ± 0.007
	$BCF_{ML/S}$	0.132 ± 0.003	0.119 ± 0.003	0.090 ± 0.002	0.059 ± 0.001
	$BCF_{YL/S}$	0.356 ± 0.008	0.199 ± 0.004	0.123 ± 0.003	0.073 ± 0.002

The soil of reference sample has a Zn content which is lying under lower limit of the above mentioned optimal range, namely 20–25 mg kg^{-1} [8, 9]. However, the Zn concentration found in the root and in the young leaves is considerably greater. The corresponding TF and BCF values are also considerably higher as compared to other parts of the plant. These data indicate that the available low amounts of Zn are concentrated in the root and subsequently are sent mainly to the young leaves, *i.e.* to the growing parts of the plant. Possibly, the available zinc amounts existing in the aerial part of the plant are also re-distributed between different organs in order to sustain the development of the young leaves and, implicitly, the development of the plant as a whole. The apparent contradiction between these statements and the data in Fig. 2 that show highest development parameters over first 12 days after seeding in the case of the reference sample, can be explained in terms of critical Zn concentration in soil that is around 0.5–0.7 mg kg^{-1} (as diethylene triamine pentaacetic acid (DTPA)-extractable zinc [32]). Hence, the Zn naturally existing in the soil is largely enough to enable the plant growth in better conditions than in the Zn-stress ones.

In other terms, the above results illustrate the importance of micro-elements intake in the fertilizers: as the plant has the tendency to concentrate the micro-nutrients, their depletion in soil is expectable for further cultivation so, including

micro-nutrients in the fertilizers, in adequate amounts, enables sustainable agricultural production and avoid the degradation of soils quality.

Table 2

Pearson correlations for Fe and Zn concentrations in conditions of Zn excess
(S – soil, R – root, St – stem, ML – mature leaves, YL – young leaves)

		Zn					Fe			
		S	R	St	ML	YL	R	St	ML	YL
Zn	S	1	**0.964***	0.836	**0.966***	0.336	-0.730	-0.771	**-0.988***	-0.859
	R	0.964*	1	0.661	**0.999****	0.074	-0.528	-0.891	-0.912	-0.704
	St	0.836	0.661	1	0.669	0.798	**-0.977***	-0.348	-0.908	**-0.980***
	ML	0.966*	0.999**	0.669	1	0.086	-0.546	-0.902	-0.913	-0.721
	YL	0.336	0.074	0.798	0.086	1	-0.871	0.257	-0.473	-0.733
Fe	R	-0.730	-0.528	-0.977*	-0.546	-0.871	1	0.250	0.814	**0.972***
	St	-0.771	-0.891	-0.348	-0.902	0.257	0.250	1	0.666	0.468
	ML	-0.988*	-0.912	-0.908	-0.913	-0.473	0.814	0.666	1	0.911
	YL	-0.859	-0.704	-0.980*	-0.721	-0.733	0.972*	0.468	0.911	1

* p – value < 0.05; ** p – value < 0.01 ($N = 4$)

The data in Table 1 corroborated with Fig. 1 indicate clearly a trend of Zn accumulation in the root, especially at high contamination levels. The BCF values for stem and leaves are considerably lower than for the root. These results suggest that Zea Mays tends to accumulate Zn especially in the root even it does not act properly as an excluder, *i.e.* the root BF is not greater than 1 and the values of some translocation factors are high enough, exceeding the unity, especially at lower Zn stress. At higher Zn contamination level of the soil, the TF values tend to decrease, the BCF for root and mature leaves increased slowly but remained in the same order of magnitude, while the BCF of young leaves decreased clearly. An explanation could be that between the root and soil occurs inhibition processes of zinc ion flow in towards the plant. In general, this phenomenon occurs in the rhizosphere through formation of zinc complexes with organic acids secreted by the plant. It was also mentioned that the precipitation of Zn as insoluble compounds could occur by participation of bacterial siderophores that can chelate some heavy metals present in abundance in the soil; however, in certain circumstances the siderophores can inverse their action increasing the bioavailability of the heavy metals [33].

In Table 2 are presented the Pearson correlation values for Fe under Zn excess.

The most significant correlations are between the root and the mature leaves ($p < 0.01$), which seems to be most responsive to changes in the concentration of zinc in soil (Table 2). The fact that the correlations between roots and mature leaves are stronger than the correlation between root and stem may be related to a detoxification processes occurring in the plant (it can be seen as well from the data concerning zinc translocation from root to mature leaves where $TF_{ML/R}$ is slightly increased (Table 1)). If the correlation of Zn content in the root and stem would be stronger, then the Zn from root could easier arrive in the growing organs of the plant.

This effect can be observed in the case of zinc translocation factor from root to stem and from root to young leaves. Although, at lower concentrations of zinc in the soil (*i.e.* Zn1) $TF_{YL/R}$ and $TF_{St/R}$ reaches high values (Table 1), with increase of the Zn concentration in the soil (Zn3), $TF_{ML/R}$ and $TF_{St/R}$ decreases by 6-fold (Table 1) and, respectively, 15 times with respect to Zn1. This suggests that at high levels of zinc in the soil, the root acts as a barrier hindering the Zn access to other vegetative organs.

It should be mentioned that various transport proteins mediate Zn translocation and accumulation, such as: ZIP, HMA3, NRAMP1, YSL, HMA4, PCR1, PCR2, ZIF1, MTP1, MTP2, NRAMP3, NRAMP4. [34]

Homeostatic mechanisms are known to be involved in the regulation of Zn concentration in different maize tissues, resulting in decrease of the harmful effects for the plant of Zn excess existing in soil [35]. Zn uptake in the root cell is mediated by ZRT (Zinc regulated transporter) like protein, a ZIP type protein [36]. The detoxification mechanism leading to the decrease of Zn concentration in cytoplasm involves other important transport proteins, such as HMA3, MTP1, MTP3, ZIF1 (concentrates zinc in vacuoles) and HMA4, YSL, PCR1, PCR2 (remove zinc from cells to the extracellular space). Alternative mechanism for Zn-detoxification of maize consists in formation of Zn complexes with phytochelatins. This process occurs in cytoplasm and the resulted complex compounds are stored in vacuoles [37]. Thus, in the case of rice, HMA3 protein, mediates zinc the zinc accumulation in root vacuoles, thereby reducing its translocation to other vegetative organs [38]. A similar process is possible in other plants of the Gramineae family, including maize. If HMA4 activity is more intense than of HMA3, there is a risk to accumulate large amounts of zinc in the aerial parts of maize. In some cases, as for example in Arabidopsis, a close cooperation of HMA3 and HMA4 was observed leading to reduced levels of Zn in the aerial part of the plant [35]. In our case, taking into account the values of TF and BCF, it can be concluded that there is a certain cooperation between the proteins responsible for Zn removal from cells and those mediating Zn accumulation in vacuoles. The result of this cooperation is lower levels of Zn in aerial parts of the studied plants as compared to the root (Fig. 1, Table 1). It is interesting to observe that the values of TF and BCF tend to decrease as the Zn concentration in soil increases

suggesting an enhanced cooperation of both types of proteins as the Zn stress in soil increases. On the other hand, the relative important level of Zn observed in the aerial parts, without resulting in dramatic influence on the growth process, could be assigned to increased content in phytochelatins-complexed Zn.

In our case, a clear effect of Zn stress about the corn growth was observed, as it is show in Fig. 2. The most important correlations are between the plant height and zinc concentration in soil ($r = -0.942$), and between the plant height and the Zn concentration zinc in strain ($r = -0.924$), *i.e.* the organs related to the plant height. However, the undersizing effect of plant height induced by chemical stress is rather low and can be explained by action of different detoxification mechanisms.

The decrease of $TF_{YL/R}$ and $TF_{St/R}$ with increasing the zinc concentration in root (Fig. 1) suggests that the activity of the zinc transporter proteins to the vacuole (*e.g.* mainly mediated by HMA3) is more intense than the activity of zinc transporter which removes zinc from the cell (which can be assigned to HMA4), leading to zinc accumulation in root vacuoles. The increase of $TF_{ML/R}$ index suggests also that an important amount of zinc is moved to the aerial tissues due to HMA4, YSL, PCR1 and PCR2 activities reaching the mature leaves ($p < 0.01$). Here, the zinc accumulation occurs through very similar mechanisms as in the root. Thus, the Zn excess coming from soil is shared between the less sensible parts of the plant, *i.e.* the root and the mature leaves, a process that results in a diminished impact of the Zn onto the growing tissues, which are inherently more sensitive to the chemical stress.

Our data indicate that the zinc excess present in soil and consequently in plant decreases the iron uptake. There is a competition between the zinc and iron ions to enter the plant affecting initially the root. An explanation of the reduced iron uptake can be the formation of franklinite ($ZnFe_2O_4$), an insoluble combination that lead to lower availability of both metals. As the content of Fe found initially in the soil was considerably below the normal limit [39], lying in the range of 900 mg kg^{-1}, the blocking of part of iron ions in such an insoluble combination could explain the lower translocation levels for iron. However, the mechanisms leading to depression of Zn in stem and root are more complicated as suggested [40].

IRT1 carrier protein (a ZIP transporter) is involved in transport of both Fe and zinc. Under conditions of iron deficiency in the root, increased availability of zinc into the plant and the zinc transport and translocation are promoted. A simple model of competition of Fe and Zn ions to occupy the active sites of IRT1 or of other transport proteins could illustrate the regression of Fe ions. Therefore, it is reasonable to suppose that the excess of Zn ions existing in the extracellular space would suppress the penetration of Fe ions into the cells causing the iron deficiency [19]. This effect is noticeable particularly in the leaves, because of increased Zn concentration in strain ($p < 0.05$, Table 2). The low level of iron available in the

root leads to a further increases of Zn level in strain [41]. Thus explains the inverse correlation between the level of zinc in the stem and the Fe level from young tips ($p < 0.05$, Table 2). Hence, the inverse correlation observed between the Zn level in the stem and the Fe concentration in young leaves ($p < 0.05$, Table 2) can be understood: the iron deficiency in the root primarily affects the young leaves ($p < 0.05$), suppressing the growth of the photosynthetic structures. Generally speaking, the entire transport of the iron to all the plant organs (stem, young leaves and mature leaves) is considerably affected as the data in Table 1 show. The overall effect is a perturbation of iron absorption and translocation resulting in regression of plant growth as the plant's height data clearly shown (Fig. 2).

5. CONCLUSIONS

This study was performed to understand how can be harmful the Zn stress for the maize growth. It appears that the maize is a zinc-tolerant indicator. The study of this behavior is very important to assess the potential risks for domestic animals and human consumers. Although the study did not include observations on the cob, the investigations on corn green organs have shown that the Zn concentration exceeds maximum 2 times the normal concentration of this heavy metal in a normal cattle's diet [20] while the Zn concentration in soil exceed the maximum admissible concentration.

Based on the BCF and TF values, it can be said that maize acts rather as a Zn indicator, the Zn concentrations inside different plant organs being proportional to that existing in soil but lower than typical values for a bio-accumulator.

Elemental analysis data and physiologic observations on Zea Mays growth enabled to observe a certain change in plant metabolism in the presence of intense Zn stress. The effect of detoxification mechanisms was also clearly observed and partly compensates the effect of Zn stress.

The effect of Zn excess on the absorptions of iron ions is discussed in terms of Pearson correlations. Due to the similar mechanisms of ions absorption, transportation and accumulation, the enormous Zn excess resulted in a selective suppression of absorption of other micronutrients. The selectivity is related both to metal ion nature as well as to the plant organ. The more similar are these mechanisms, the higher are the suppression effects because Zn replaces other ions in the respective processes.

As a complex biological system, possessing a wide range of means to ensure its biochemical equilibrium even under adverse conditions, the maize plant managed itself, in some limits, the disequilibrium of micronutrients in soil. Hence, the concentration profile of the studied micronutrients in different plant organs is considerably different to that existing in growth soil and close enough to the normal limits. These profiles are correlated to Zn content in strain or in root and

suggested the complex inter-relation existing between different micronutrients under the Zn stress conditions. Thus, the Pearson's correlations inferred useful information about the transport peculiarities of the each microelement, enabling a broad understanding of the collective transport of microelements and their inter-relations under Zn stress in a living complex organism as is a maize plant.

Besides their direct signification concerning the effect of chemical stress about the plant development and hence on the biosphere, our result illustrate the enormous ability of plants to adapt to difficult conditions enabling the environmental regeneration subjected to chemical stress resulted from human activities.

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