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Genotype and Environmental Effects on Cadmium Concentration in Maize

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Abstract: Seven parents and their 21 F_1 diallel crosses of maize were grown under field conditions in the 2001 and 2002 growing seasons on two soils mutually air-distanced 800 m (B1 = fluvisol and B2 = stagnic albeluvisol; pH in KCl = 7.02 and 3.85, humus = 2.75 and 2.02, $CaCO_3$ = 11.4% and 0, for B1 and B2, respectively). Also, the B1 and B2 were differently in NH_4Acetate-EDTA soluble fraction ($mg \cdot kg^{-1}$: calcium 25,500 and 2,300; zinc 1.61 and 0.53; cadmium 0.195 and 0.064, respectively). The experiments were conducted in four replicates (the basic plot 16.8 m^2) in a randomized complete block design. The ear-leaf was taken at the beginning of silking and grain samples at maturity. Mean leaf-Cd ($mg\ Cd \cdot kg^{-1}$ in dry matter) were 0.102 and 0.072, for 2001 and 2002; 0.064 and 0.195, for B1 and B2, while differences in level of genotype were from 0.040 to 0.581 (the parents) and from 0.046 to 0.171 (the hybrids). Six hybrids of Bc707-1 had considerably higher leaf-Cd in comparison with six hybrids of Bc265-1 (means 0.100 and 0.050 respectively). Grain-Cd was under detectable range (< 0.040) with exception of Bc707-1 parent on the B2 soil (0.17 $mg\ Cd \cdot kg^{-1}$).

Key words: Cadmium, genotype, grain leaf, maize, soil effects, year effects.

1. Introduction

Heavy metal contamination is a serious environmental problem that limits crop production and endangers human health. Cadmium (Cd) is a non-essential element that negatively affects plant growth and development. It is recognized as an extremely significant pollutant due to its high toxicity and large solubility in water [1]. It is generally acknowledged that dietary intake of Cd is the major source of Cd exposure for the general population. The tolerable daily intake of Cd is 1 ug Cd kg^{-1}/body/weight, an equivalent to a daily intake of 70 ug Cd for an adult of 70 kg [2]. The organic matter, clays and hydrous oxides absorb metals and for this reason, soils with higher metal absorption capacity have lower potential for uptake of metals by plants [3].

Besides environmental factors, heredity has important role in uptake of mineral elements in plants [4]. Natural variation occurs in both the uptake and the distribution of Cd the food groups that contribute largely to dietary Cd intake are cereals, potato, vegetables and fruit, with some exceptions [5, 6]. It was estimated that non-polluted soil solutions contain Cd concentrations ranging from 0.04 to 0.32 mM [7] also, heavy metals uptake by plants decreases with the increase of soil pH [8].

In crop species and cultivars within species [9-11] Plant species and varieties vary widely in tolerance to excess of Cd into he growth medium [12]. Substantial genotypic variation in Cd accumulation in leaf and grain in maize [13] suggest that genetic factors determine differences in Cd accumulation.

The objective of this study was to examine Cd concentrations in leaf and grain of 28 maize genotypes grown under field conditions during two growing seasons. Grain yield, phosphorus and potassium status

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in leaf and grain were shown by the previous study [14].

2. Material

2.1 The Field Experiment

Total 28 domestic maize genotypes of Bc-Institute for Breeding and Production of Field Crops (seven inbred lines and their 21 F_1 diallel crosses, designated from 1 to 7 and from 8 to 28, for the parents and their hybrids, respectively) were grown under field conditions during the 2001 and 2002 growing seasons on two soil types (fluvisol an stagnic albiluvisol: mutually air-distance between two experiments about 800 m) of Northwestern Croatia (Sesvetski Kraljevac, Zagreb County). Relative proximity of sites minimized climatic differences, thus emphasizing genotypic and edaphic effects. The experiments were conducted in four replicates (the basic plot 16.8 m^2 = three 8-m rows) in a randomized complete block design. Both experiments were fertilized uniformly ($kg \cdot ha^{-1}$: 183 N + 100 P_2O_5 + 150 K_2O). The fertilizer NPK 7:20:30 was ploughed down in autumn (500 $kg \cdot ha^{-1}$), urea was disced by disk harrow (250 $kg \cdot ha^{-1}$) in spring and CAN (calcium-ammonium nitrate 27% N) was added by top dressing with interrow soil tillage at early growth stage of maize. Maize was sown at beginning of May by 4-rows pneumatic sowing machine (Wintersteiger-type Plotspider). At 3-5 leaf stages maize crop was thinned to planned plant density 63,523 $plants \cdot ha^{-1}$ (109 plants/basic plot). Maize was harvested at full maturity (depending on year and soil type, in middle of October and the first half of November). Usual crop management practice for maize was applied in both trials. Water content in grain was measured by Burrows Digital Moisture Computer-Model 700. Grain yields were calculated on 14% grain moisture basis. Grain yield and nutritional status of maize (P-, K-, Zn- and Fe-concentrations in leaf and grain) were shown by the previous studies [14, 15].

2.2 Soil and Weather Characteristics

The used soils are, according criteria described by Vukadinovic and Loncaric [16], very acid (stagnic albeluvisol) and neutral (fluvisol) reaction, both low in humus and good supplied with N, P and K. Mobile fraction of individual elements differences ($mg \cdot kg^{-1}$ for fluvisoil and albeluvisol, respectively) were considerable for calcium (25,500 and 2,300), manganese (328 and 76) and zinc (1.61 and 0.53). Also, a three-fold higher concentration of mobile Cd in fluvisol (0.195 and 0.064) was found (Table 1). Soil and weather characteristics, including the profile characteristics, were elaborated in detail by the previous study [14].

The 2001 and 2002 growing seasons were specific regarding precipitation and temperature regimes. With that regard, low precipitation in July-August period (only 40% in comparison with 30-year mean) and high air-temperartures in August were main characteristics of weather condition in 2001. However, the next growing season was considerably more favorable for maize growing because of adequate precipitation in these two months period (150% of 30-year mean) and lower air-temperature in August (Table 2). In general, low yields of maize are in close connection with lower precipitation and the higher air-temperatures in summer period [17-19].

3. Methods

3.1 Sampling and Chemical Analysis

Two soil samples (0-30 cm) representing each soil type were taken by auger at start of the experiment and before fertilization. The ear-leaf was taken at the beginning of silking stage (20 leaves were randomly chosen per plot), while grain samples were taken from mix of five randomly chosen ears per plot for chemical analyses.

The total amount of individual elements in the leaf and grain samples after microwave digestion using concentrated HNO_3 + H_2O_2 was measured by the ICP-AES technique by Jobin-Yvon Ultrace 238 ICP-OES spectrometer in the laboratory of the Research

Table 1 Soil characteristics.

Soil	Soil (0-30 cm) properties (B1 = fluvisol; B2 = stagnic albeluvisol)								
	pH		Humus (%)	NH_4Acetate–EDTA (pH 4.65) extraction (mg·kg^{-1})					
	H_2O	KCl		$CaCO_3$	Ca	Mg	Mn	Zn	Cd
B1	7.86	7.02	2.75	11.4	25,500	280	328	1.61	0.195
B2	4.98	3.85	2.02	0	2,300	279	76	0.53	0.064

Table 2 Weather characteristics and long-term means (Zagreb-Maksimir* Weather Bureau).

	Jan.-Mar.	Apr.	May	June	July	Aug.	Sept.	Apr.-Sept. total	Apr.-Sept. mean
The growing season 2001									
mm	193	79	71	121	55	14	172	511	-
°C	6.4	10.6	17.8	18.4	21.8	22.5	14.4	-	17.6
The growing season 2002									
mm	101	131	86	71	124	143	78	633	-
°C	5.4	10.8	18.4	21.1	21.9	20.8	15.4	-	18.1
The long-term means (30-years: 1961-1990)									
mm	144	64	79	100	83	95	79	500	-
°C	2.3	10.6	15.3	18.5	20.1	19.3	15.8	-	16.6

* about 15 km air-distance from Sesvetski Kraljevec in W direction. mm, °C: precipitation (mm) and mean air-temperatures (°C) in Zagreb-Maksimir*.

Institute for Soil Science and Agricultural Chemistry (RISSAC) of Hungarian Academy of Science and Arts in Budapest, Hungary. Detection limit of applied method for Cd was 0.040 mg Cd·kg^{-1}. Grain Cd was below detection limit with exception of Bc707-1 genotype on the stagnic albeluvisol.

3.2 Statistical Analysis

The data were statistically analyzed by ANOVA and treatment means were compared using *T*-test and LSD at 5% and 1% probability levels.

4. Results

Concentrations of Cd in maize leaf were under considerable effects of the growing season, soil and genotype (Table 3).

Under environmental conditions of the 2001 growing season, leaf-Cd was about 40% higher than in 2002 (0.102 and 0.072 mg Cd kg^{-1}, respectively). Precipitation and temperature regime differences between two growing seasons (Table 2) could be responsible for these effects because the experiments were conducted at same place.

Although in albeluvisol the lower concentration of mobile Cd-fraction was found (Table 1), maize grown on this soils contained three-fold more leaf-Cd in comparison with maize on the fluvisol (0.195 and 0.064 mg Cd mg^{-1}, respectively).

In our study, considerable effects of genotype and heredity on leaf-Cd in maize were found (Table 3). The Bc707-1 and the Bc706-9 parents of maize hybrids had considerably higher leaf-Cd (0.581 and 0.105 mg Cd·kg^{-1}, respectively) than remaining five parents (mean 0.056 mg Cd·kg^{-1}). These differences correspondingly reflected on leaf-Cd status of their hybrids. For example, the hybrid 25 (Bc707-1 × Bc706-9) had the highest leaf-Cd (0.171 mg Cd·kg^{-1}) among 21 hybrids (mean of remaining 20 hybrids: 0.065 mg Cd·kg^{-1}). Also, six hybrids including the Bc707-1 as parent had under identical environmental conditions the considerable higher leaf-Cd (mean 0.100 mg Cd·kg^{-1}) in comparison with remaining 15 hybrids (mean 0.058 mg Cd·kg^{1}). On the other hand, the Bc265-1 parent had the lowest leaf-Cd (0.04 mg

Table 3 Impacts of year, soil type and maize genotype (the inbred lines and their progeny) on leaf-Cd concentrations (the ear-leaf at silking), grain-Cd concentrations and grain yields.

C		Leaf-Cd concentrations (mg Cd·kg^{-1})					Grain yield (kg·ha^{-1})				
Code	The parents	A1	A2	B1	B2	Average C	A1	A2	B1	B2	Average C
	♀ × ♂	AC interaction		BC interaction			AC interaction		BC interaction		
a	Bc265-1	0.040	0.040	0.040	0.040	0.040	5,657	5,954	6,869	4,743	5,806
b	Bc779-4	0.073	0.054	0.040	0.086	0.063	5,605	5,052	6,136	4,521	5,328
c	Bc703-19	0.066	0.050	0.041	0.075	0.058	5,448	4,845	5,476	4,817	5,147
d	Bc706-9	0.141	0.069	0.066	0.144	0.105	4,456	4,478	5,055	3,879	4,467
e	Bc737-5	0.078	0.040	0.049	0.069	0.059	5,417	4,669	5,861	4,226	5,044
f	Bc539-1	0.070	0.046	0.047	0.069	0.058	5,505	5,511	5,962	5,055	5,509
g	Bc707-1	0.611	0.550	0.149	1.013	0.581	6,161	5,500	6,323	5,338	5,831
8	a × b	0.051	0.040	0.040	0.051	0.046	9,864	10,493	11,557	8,800	10,179
9	a × c	0.057	0.040	0.041	0.056	0.049	8,408	9,128	9,601	7,935	8,768
10	a × d	0.064	0.040	0.045	0.059	0.052	8,175	9,350	9,437	8,088	8,763
11	a × e	0.055	0.040	0.040	0.055	0.047	8,603	9,486	10,059	8,030	9,045
12	a × f	0.055	0.040	0.042	0.052	0.047	9,188	9,755	10,631	8,312	9,473
13	a × g	0.078	0.040	0.042	0.075	0.059	7,852	9,023	9,712	7,163	8,438
14	b × c	0.086	0.046	0.056	0.076	0.066	9,263	10,709	11,271	8,701	9,986
15	b × d	0.089	0.044	0.056	0.076	0.066	9,189	10,838	10,876	9,151	10,014
16	b × e	0.094	0.040	0.061	0.072	0.067	8,353	9,454	9,926	7,881	8,904
17	b × f	0.084	0.040	0.049	0.075	0.062	9,841	10,767	11,246	9,362	10,304
18	b × g	0.119	0.084	0.067	0.135	0.101	8,757	10,782	10,686	8,853	9,770
19	c × d	0.089	0.046	0.049	0.086	0.068	8,537	9,144	9,705	7,976	8,841
20	c × e	0.071	0.044	0.043	0.072	0.058	8,695	9,779	10,471	8,004	9,238
21	c × f	0.076	0.040	0.050	0.066	0.058	8,857	9,575	10,364	8,069	9,217
22	c × g	0.110	0.067	0.062	0.115	0.089	8,321	9,357	9,461	8,217	8,839
23	d × e	0.084	0.042	0.060	0.066	0.063	8,347	9,214	9,583	7,979	8,781
24	d × f	0.063	0.042	0.051	0.054	0.052	8,430	10,279	10,054	8,656	9,355
25	d × g	0.176	0.166	0.099	0.244	0.171	7,696	9,812	9,712	7,796	8,754
26	e × f	0.079	0.052	0.055	0.076	0.066	9,816	9,870	10,494	9,192	9,843
27	e × g	0.101	0.090	0.067	0.124	0.096	7,975	9,035	9,463	7,546	8,505
28	f × g	0.093	0.082	0.066	0.109	0.087	8,004	9,330	9,541	7,793	8,667
Average A		0.102	0.072				7,872	8,614			
Average B				0.056	0.118				9,126	7,360	
AB interaction		A1B1	A1B2	A2B1	A2B2		A1B1	A1B2	A2B1	A2B2	
		0.069	0.135	0.044	0.100		9366	6379	8887	8342	

Statistical analysis ANOVA	A	B	C	AB	AC	BC	A	B	C	AB	AC	BC
LSD 5%	0.006	0.006	0.027	n.s	n.s	0.041	256	n.s.	1143	363	n.s.	n.s.
LSD 1%	0.008	0.008	0.037	n.s.	n.s.	0.060	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Grain-Cd concentrations (mg Cd·kg^{-1})

The parents (a – g): below detection limit (< 0.040 mg Cd·kg^{-1}) with exception the parent g grown on the B2 soil (0.19 and 0.17 mg Cd·kg^{-1}, for 2001 and 2002, respectively).

The hybrids (8-28): below detection limit for all the tested treatments.

A: Year; A1: 2001; A2: 2002; B: Soil; B1: fluvisol; B2: stagnic albeluvisol; C: maize genotypes; a – g: the parents; 8-28: the hybrids of these parents.

Cd·kg^{-1}) and it is 15-fold lower than in the Bc707-1. Consequently this properties, the six hybrids containing the Bc265-1 as parent (1-6) had mean only 0.05 mg Cd·kg^{-1} in leaf or 50% lower than the hybrids of the highest Cd-leaf parent.

Grain-Cd was considerably lower and it was under detectable range of the applied method (< 0.040 mg Cd·kg^{-1}) for tested 28 genotypes with exception of the highest leaf-Cd parent (Bc707-1) on stagnic albeluvisol soil (2-y mean 0.17 mg Cd·kg^{-1}).

In our study, grain yield of maize was higher in 2002 (Table 3) for 10% (7,872 and 8,614 kg·ha^{-1}, for 2001 and 2002, respectively), probably because of more favourable weather conditions (Table 2). Also, yield was higher on fluvisol for even 24% (9,126 and 7,360 kg·ha^{-1}, for fluvisol and albeluvisol respectively). Yield of seven parents was for 42 % lower than yield of their 21 hybrids (means 5,305 and 9,223 kg·ha^{-1}, respectively). Mean yield of six hybrids with included either the highest leaf-Cd parent Bc707 or the lowest leaf-Cd parent Bc265-1 was 8,829 and 9,111 kg·ha^{-1} respectively, but the difference is non-significant. Also, low negative correlation (comparison 28 pairs in level of genotype effects) between leaf-Cd and yield was found ($r = -0.25$).

5. Discussion

Differences of leaf-Cd in maize under two soil conditions is possible to explain by soil pH effects and soil nutritional status on Cd uptake by crops. A review of Cd in soil shows that the mobility of Cd in soil consistently increases with decreasing soil pH [20]. Grain Cd concentrations of wheat from 8 long-term field trials decreased about 4-fold between pH 4.9 and pH 6.2 but did not show any further trend at pH > 6.2 or pH < 4.9 [21]. Field surveys carried out in different parts of the world did show that soil Cd usually explains less than 20% of the variability of crop Cd [22-24]. Different surveys of crop Cd concentrations have identified correlations between crop Cd and other soil properties such as soil pH, % carbon, soil Zn, etc. [23].

Zinc deficiency increases Cd uptake by crops. McGrath and Loveland [25] found that application of small quantities of Zn (up to 10 kg Zn·ha^{-1}) reduced wheat grain Cd by approximately two times. Also, high wheat grain Cd concentrations exceeding 0.1 mg Cd·kg^{-1} grown in uncontaminated soils in France was explained by marginal Zn deficiency in that area [24]. Street et al. [26] found that uptake of Cd by maize was less in one of the most acid soils that also had the highest organic matter content. By these findings (soil pH, organic matter and zinc effects on Cd uptake by crops) could be explained the higher leaf-Cd in our study on the stagnic albeluvisol compared to the fluvisol. Also, Root et al. [27] felt that Cd-induced chlorosis in maize leaves could be due to change of Fe:Zn ratios. In others, Cd toxicity appeared to induce P deficiency. Cd has been shown to interfere with the uptake, transport and use of several elements (Ca, Mg, P and K) and water by plants [28]. Our two tested soils had considerable differences in status of mobile fraction of some elements and they could contribute to different Cd status in maize.

Kovacevic et al. [29] tested Ca, Mg, S, Zn, Mn, B, Mo, Sr, Ba and Cd status in leaf of ten parents of maize hybrids. Depending on the genotype, leaf-Cd was in range from 0.04 to 0.98 mg Cd·kg^{-1}. As in our study, the genotypes Bc707-1 and Bc706-9 had the high leaf-Cd (0.98 and 0.26 mg Cd·kg^{-1}, respectively), while the genotype Bc 265-1 characterized low leaf-Cd (0.06 mg Cd·kg^{-1}).

Bukvic et al. [30] reported regarding harmful element contents in soil and maize samples collected from five field experiments in the 1993-1998 period. In general, low leaf-Cd was found in maize (0.084 mg Cd kg^{-1}: mean of 160 samples) and depending on the experiment it was in range (mean values) from 0.04 to 0.14 mg Cd·kg^{-1}.

Zhang and Song [13] found also different Cd accumulation in root, leaf, stem and grain among three maize genotypes in maturing stage. The concentration of Cd in leaves of the B84 × Os6-2 F_4 progeny varied from 0.1 to 1.7 mg·kg^{-1}. These amounts were below critical concentrations of 5-10 Cd mg·kg^{-1} for plants suggested by Sauerbeck et al. [31].

Soric et al. [32] tested variation for Cd concentration in leaves of maize genotypes. Depending on the genotype leaf-Cd was in range from 0.1 to 1.7 mg·kg^{-1}.

Crops as sunflower, flax, rice and durum wheat have been identified as accumulators of Cd, frequently contained more than 0.10 mg Cd·kg^{-1} dry matter [33, 34].

In general, rice can accumulate high concentrations of Cd but also contains very low concentrations of Zn, Fe and Ca [35]. For this reason, diet relying primarily on rice deficiencies of these elements can lead to increases Cd uptake by crop.

Selection of low-Cd field crop cultivars is of importance for human health. However, low-Cd characteristic has to be combined with many other essential properties such as high yield, quality and resistances to diseases, insects, stalk lodging, droughts etc. In addition, Cd status in crops may be affected by other selection activities. For example, selection for Al and acid soil tolerances often is in connection with excess of Cd accumulation under acid soil conditions. Also, soil management practice as application of Cd-containing fertilizers, the use of high-chloride irrigation water can increase Cd accumulation in plants. Application of zinc fertilizers with aim of correction Zn deficiency and liming are useful management practices for minimizing Cd uptake by crops. Also, by breeding programme of improvement uptake of essential trace elements in grain, for example zinc, may contribute lower Cd accumulation due to antagonism between Zn and Cd uptake by crops [36].

6. Conclusions

Cadmium uptake by plants is under considerable influences both environmental and hereditary factors. By correspondingly plant breeding programmes is possible to creation cultivars of main field crops characterizing low-Cd uptake and their growing under less favorable conditions for Cd uptake by plants (less acid soils with the higher organic matter contents and balanced nutritional status) could be contribute to minimizing Cd contamination of food and human population. Also, testing of Cd status of the commercial and the most frequently used cultivars of the field crops growing in the varietal field experiments are source of useful information regarding their affinity for Cd uptake under identical environmental conditions.

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