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Interaction between Cadmium and Zinc in Triticale (X *Triticosecale wittmack*) Grown under Field Conditions

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An investigation of the interaction between cadmium (Cd) and zinc (Zn) in triticale, a field experiment was conducted. Cadmium and zinc at tillering stage (3-4 leaf) applied by foliar application (individually and jointly) to triticale in the following doses (in kg/da): Cd-0,1,2,4 and 6, Zn-0,1.5 and 3. Flag leaf samples were taken at heading stage, and grain samples were also taken after harvest. The concentration of Cd and Zn in flag leaves and grain was measured by ICP-AES. No phytotoxic symptoms were observed during experiment. The grain yield was used as a parameter of growth and Cd and Zn application did not affected the grain yield of triticale. Cadmium concentrations in flag leaf and grain increased with increasing Cd application but decreased with increasing Zn application. Cd and Zn application unchanged nitrogen and potassium concentration in triticale. The effect of different doses of Cd and Zn application on grain Cd content was found statistically significant. Increased Cd doses decreased Zn content in grain.

Key Words: Triticale, Cadmium, Grain, Zinc.

INTRODUCTION

In recent years, there has been increasing awareness and concern over heavy metal contamination of soils and its effects especially for food chain. High concentrations of heavy metals in agricultural soils can occur naturally or *via* atmospheric deposition or the application of metal-contaminated sewage sludges, Cd-rich phosphate fertilizers and animal manures[1,2]. Cadmium is one of the toxic metals for plants, animals and humans.

Commercial fertilizers are considered to be a major input source of Cd in agricultural soils in Turkey. Nutrient-deficient agricultural soils in Turkey have been remediate especially through the application of fertilizers containing N-P-K. There is no upper Cd concentration limit for N-P-K fertilizer used in Turkey. Koleli *et al.*[3] studied Cd concentration in phosphate rock, phosphoric acid and phosphorous fertilizers in Turkey and reported that the Cd concentrations were above the standard value of 8 mg/kg fertilizer in 10 of total of 14 fertilizers analyzed, and were close to this value in 2 fertilizers (7.5 mg/kg fertilizer). Many studies have shown that the use of Cd-containing fertilizers increased Cd uptake by plants[4] and also agricultural management practices that directly affect Cd concentrations and availability in the soil may influence Cd accumulation by crops[5]. A number of soil factors have been shown to affect the availability of Cd to plants. Increasing pH favours the adsorption of Cd to metal binding sites and decreases the partition of Cd to soil solution[6]. Other soil properties that can influence Cd availability include the contents of soil organic matter and Fe and Mn oxides[7-9]. The concentration of Zn in soil can affect Cd uptake by plants, presumably due to competition between these two metals for uptake and transport inside the plant[10,11].

Several studies have investigated the relationships between various soil characteristics and their uptake and transport of Cd. Difference levels of uptake and accumulation of cadmium have been shown both among plant species[5,12,13] and genotypes of a given species[14,15]. Therefore, the selection of plant genotypes with high ability to repress root uptake and shoot transport of Cd is a reasonable approach to alleviate adverse effects of Cd toxicity in crop plants. One of these plants is triticale. Triticale (X *Triticosecale wittmack*) is a cool climate crop produced as the result of crossing studies which aimed to genetically combine the efficiency and quality of wheat and the high adaptation ability of rye[16]. Triticale has a high yield potential in field conditions where wheat and barley cannot be grown efficiently and with high quality. Triticale is, in general, more tolerant than wheat and barley for biotic and abiotic stresses[17]. Breeding for marginal areas (acidic or alkaline soils), micronutrient deficiencies (Cu, Zn or Mg) or toxicity (boron) and drought stress are the main objectives of most spring- and winter-triticale breeding programmes in the world[18]. Because of its mentioned characteristics, triticale has relatively less input needs and it is an environment friendly product[19].

According to the data for the year 2005 triticale was produced on an area of 3,517 million ha in the world with a production of 13,47 million tones, the average yield[20] being 3,830 kg/ha. Triticale area in Turkey was estimated at 10000 ha at the end of the year 1990s. Nowadays, the area growing triticale has reached *ca.* 160000 ha and it is becoming one of the main cereals after wheat and barley in Turkey[18]. Since triticale is a new crop for Turkey, its production is not as diverse as could be expected. In this case, there are few researches on triticale in Turkey. Demir *et al.*[21] point out that in the trials conducted in different locations of the Aegean region and Diyarbakir district in Turkey, triticale yields were higher than wheat (5-44 %) and (5-71 %), respectively[21].

In contrast to Cd, Zn is essential plant nutrition and is involved in several metabolic processes[12,22]. Zinc deficiency is the most widespread micronutrient deficiency in cereals. In Turkey, 50% of arable soils are zinc deficient[23]. The Zn quantities removed by crops are usually not fully replenished by fertilization in agricultural soils. Zinc deficiency in soils may enhance Cd absorption and transport in crop plants. Because of chemical similarity between Cd and Zn, many studies have been conducted to determine if a Cd-Zn interaction exists in soil-plant systems[24,25] and also this association of cadmium and zinc in the environment can lead to interaction between Cd and Zn during plant uptake, transport from roots to above ground parts, or accumulation in edible parts[26].

The transfer rate of cadmium from soil to the plant is very high, is easily taken by plants and accumulated in edible parts of the plant even in very low concentrations especially in case of zinc deficiency, shows that this metal has a great potential in terms of environmental health[10,27]. The amount of Cd accumulated in plants changes according to the plant species. Plants which were applied high concentrations of Cd generally become short, their leaves become small, chlorosis occurs and the leaf colour changes to brown. In most environmental conditions, Cd enters first plant roots and consequently Cd is likely to experience damage first in the roots[5]. In root tip cells of *Allium cepa*, Cd damaged nucleoli and, in rice, it altered the synthesis of RNA and inhibited ribonuclease activity[28].

Cd also reduced the absorption of nitrate and its transport from roots to shoots, by inhibiting the nitrate reductase activity in the shoots[29]. The inhibition of root Fe(III) reductase induced by Cd led to Fe(II) deficiency and it seriously affected photosynthesis[30]. In a very general way, Cd in plants causes leaf roll and chlorosis, and reduces growth, both in roots and in stems[31]. High retention of Cd is not utilized in plant roots is particularly desirable in forage, cereal and vegetable crops, thus reducing Cd burdens to animal and man[10,25].

While the total cadmium concentration allowed in agricultural soils is 3 mg/kg, generally 0.1 mg/kg of cadmium exist in soils[32]. It was determined that increased amount of zinc significantly decreased the amount of Cd transferred from durum wheat sprouts to the roots and this situation was the result of the Zn*Cd interaction through phloem transfer tubes[12]. The maximum Cd concentration allowed which is determined for all the cereal products is 0,05 mg/kg grain. 12-18 % of the Cd in the green parts of cereal products is transferred to the grain[33]. It was determined that the application of Zn to soil decreased the concentration of Cd in the grain, leaf, stalk and the root of wheat[34] and the resistance of the cereals to cadmium toxicity decreased in the following order: rye > triticale > barley > oat > bread wheat > durum wheat. Growing of plants under conditions of zinc deficiency enhanced sensitivity of cereals to Cd toxicity[35]. Interactions of Cd-Zn and their accumulation in plant parts in solution culture or in pot experiment had been reported earlier[24,27,36-40]. However, there is little information about the interactions between Cd and Zn in triticale under field conditions. The present field study was conducted to examine the nature of the interaction between Cd and Zn in triticale grown under field conditions. We choose triticale as a test plant due to being a kind of crop which has become increasingly widespread in the region, being able to grow under the conditions which restricts the growth of other crops and for having the ability of high yield and also it was chosen because it has been thought[41] that it would be resistant to Cd.

EXPERIMENTAL

A field experiment was conducted within a farm of Konya Agricultural Research Institute located in the central Anatolia of Turkey on triticale (X *Triticosecale wittmack* cv. Tatlicak-97). The mean annual precipitation, moisture and temperature were 350 mm, 55.2% and 12.2ºC, respectively. This region is considered important croplands because most cereals for the local people are produced there. A triticale as a test plant is chosen as an alternative crop in marginal areas for Turkish farmers.

Soils included on the study site are generally uniform alluvial soils. To test some initial characteristics of the soil, soil sample was vertically collected from 0-20 cm depth, dried in air, sieved to pass a 2 mm screen and mixed well before being subsamples. Some initial characteristics of the soil are as follows: pH (1:2.5) was 7.9 (moderately alkaline), EC was 0.34 mmhos/cm (little salty), texture class was sandy loam, organic matter was 1.03 % (low) and carbonate content was 12.87 % (moderately). Available P_2O_5 was 6.41 mg kg^{-1} (moderately), soluble K_2O was 108.45 kg da^{-1} (moderately). DTPA-extractable Zn was 0.64 mg kg^{-1} (sufficient) and DTPA-extractable Cd was below the detection limit.

Planting was done in half of October. All treatments were replicated three times in a randomized blocks experiment design. The applications were made in triplicate on 3*3 m plots separated by 1.5 m intervals within rows in order to minimize the effect of fertilizer diffusion.

To insure proper growth of triticale, N and P fertilizer in the form of DAP at 10 kg da^{-1} was applied during planting and NH_4NO_3 at 4.3 kg da^{-1} was applied about 4 mounts after planting. Experiment consisted of five levels of Cd as $CdSO_4.8H_2O$ (0.0 (Cd_0), 1.0 (Cd_1), 2.0 (Cd_2), 4.0 (Cd_4) and 6.0 (Cd_6) kg Cd da^{-1}) and three levels of Zn as $ZnSO_4.7H_2O$ (0.0 (Zn_o), 1.5 ($Zn_{1.5}$) and 3.0 (Zn_3) kg Zn da^{-1}) by a pulverizator at tillering stage (3-4 leaf; steam elongation) at about five mounts after planting, Zn and Cd applied with one week intervals, respectively.

The plant growth parameters (such as emergence, flowering, heading and plant height, head height) were recorded. Flag leaf samples were taken at heading stage. Grain samples were also taken at the latter stage after mature. Harvesting was carried out after eight mounts from planting.

The total grain yield was also determined. Samples of flag leaves and grain were dried at 70ºC and ground. Dried plant samples were digested using a H_2SO_4 and H_2O_2 mixture[42]. Aliquats were diluted and analyzed for Cd and Zn using inductively coupled plasma atomic emision spectrophotometry (Varian Vista AX ICP-AES). The detection limit for both Cd and Zn was 0.3 µg/L. In addition, grain samples were analyzed for P, N and K, flag leaves were analyzed only for P and K but N was not analyzed.

All data were analyzed using the statistical package GENSTAT and MSTAT program. Least significant difference (LSD) was used to compare the main treatment and interaction effects at $p < 0.05$.

RESULTS AND DISCUSSION

During the experiment, crop growth parameters (such as emergence, heading, flowering, plant height, head height) were recorded. Since the statistical analysis showed that the effect of Cd and Zn application on plant height, head height and 1000-grain weight) was not significant, these data were not included in the other data. Any phytotoxic symptoms were not detected during the experiment.

Grain yield: The grain yield was used as a parameter of growth and the results are shown in Fig. 1. Grain yields were not significantly affected by foliar Cd and Zn applications and Cd-Zn interaction were statistically not significant (Fig. 1). At Cd_0 doses, Zn_1 and Zn_2 application, a contrast to Zn_0, increased grain yields 73 and 40 %, respectively. Grain yield of Cd_0Zn_0 application was 223.5 kg/da and also maximum grain yield was obtained at Cd_1Zn_3 application (388 kg/da) and at Cd_0-$Zn_{1.5}$ application (387 kg/da). Although there was statistically no difference found between the yield values, increased doses of zinc increased the yield but cadmium doses generally decreased the yield. Yield obtained at Cd_1Zn_3 dose was higher 74 % than Cd_0-Zn_0 application. Results obtained for grain yield were similar to 1000 grain weight (these data shown not). The effects of foliar-applied Cd and Zn on plant Cd, Zn, N, P and K concentration are shown seperately for flag leaf and grain in Table-2.

Zinc content of flag and grain: In the Zn_0 dose increasing cadmium applications decreased the zinc content in the leaves and the grain, however, increases relative to the control were observed at the 1.5 ve 3 kg da^{-1} applications of zinc. These increases showed decrease with increased doses of cadmium. Köleli *et al.*[35] stated that zinc applied to the soil decreased the green part Cd concentration; however the green part Cd concentration increased with the increase of the cadmium dose.

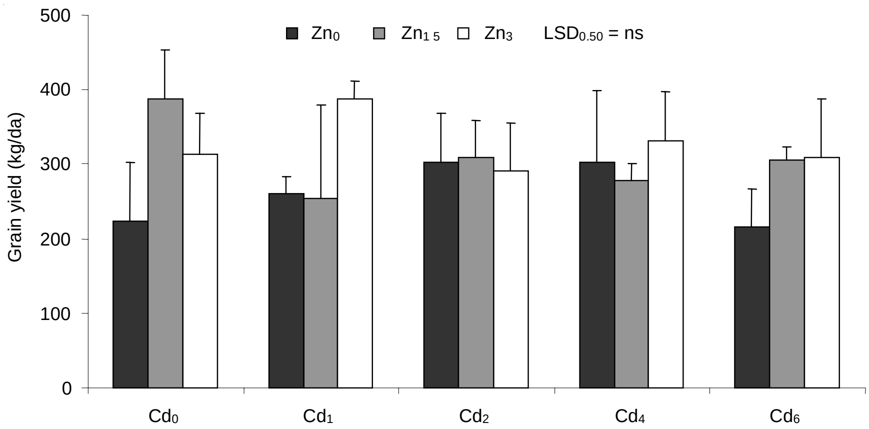

Fig. 1. Effect of different doses of Cd and Zn application on grain yield of triticale. Error bars represent ± SE of triplication (n = 3)

Cadmium content of flag and grain: While the leaf Cd content decreased with increased doses of zinc, leaf Cd content significantly increased with the Cd_0 dose of cadmium compared to the Cd_6 dose. However the increased doses of zinc negatively affected the leaf Cd content. The value, which was 0.53 mg kg^{-1} at the Zn_0 Cd_1 dose increased to 44.43 mg kg^{-1} at the Zn_3 Cd_6 dose. A similar effect was also seen in the grain Cd content and statistically significant differences were observed between the Zn-Cd applications ($p < 0.05$). At this point we can say that Zn application negatively affected the Cd content in the leaves and in the grain (Table-1).

Phosphorus contents of flag and grain: Application of increased doses of zinc decreased the phosphorus content in the leaves and in the grain but at the increased doses of cadmium application, increases were observed at the Zn_0 and Zn_1 doses; however these increases are not statistically significant.

Potassium contents of flag and grain: While the potassium content in the leaves did not change with Zn and Cd applications, K content in the grain slightly decreased with cadmium applications.

Nitrogen contents of grain: Increased doses of cadmium decreased the nitrogen content in the grain at the Zn_0 dose, on the other hand, at the increased doses of zinc a slight increase was observed only at the Cd_4 application. However, these increases are not statistically significant.

Cd and Zn uptake: Plant zinc and cadmium uptake increased with increased doses of zinc compared to Zn_0 Cd_0. Although there were significant differences ($p < 0.01$) among zinc doses and among cadmium doses in cadmium uptake, Zn*Cd interaction was found statistically insignificant (Fig. 2). Zinc uptake in the grain, however, decreased with increased doses of cadmium.

TABLE-1
Cd, Zn, N, P and K CONCENTRATION OF GRAIN AND FLAG LEAVES OF TRITICALE GROWN UNDER FIELD CONDITIONS. ERROR BARS REPRESENT ± SE OF TRIPLICATION (n = 3)

Zn dose (kg/da)	Cd dose (kg/da)	Cd	Zn (mg/kg DW)	P	K (%)	N (%)
Flag leaf						
0	0	N.D.*	13.87 ± 9.15	2041.60 ± 366	1.65 ± 0.03	
	1	0.53 ± 0.30	21.59 ± 5.41	1831.07 ± 121	1.73 ± 0.07	
	2	1.80 ± 0.06	10.30 ± 2.76	2381.87 ± 590	1.76 ± 0.08	
	4	3.73 ± 0.00	11.90 ± 5.26	2041.60 ± 458	1.72 ± 0.02	
	6	4.97 ± 4.31	10.58 ± 0.77	2229.33 ± 515	1.72 ± 0.09	
1.5	0	N.D.	14.40 ± 4.99	2006.40 ± 275	1.8 ± 0.05	
	1	4.77 ± 1.38	22.78 ± 0.00	2174.53 ± 469	1.7 ± 0.04	
	2	8.37 ± 2.61	22.75 ± 2.42	1915.44 ± 18	1.7 ± 0.09	
	4	32.08 ± 6.85	27.65 ± 0.63	1883.20 ± 88	1.7 ± 0.04	
	6	40.20 ± 2.68	41.22 ± 1.33	2417.07 ± 287	1.8 ± 0.05	
3.0	0	N.D.	33.48 ± 7.81	1736.53 ± 147	1.8 ± 0.18	
	1	3.98 ± 0.00	33.24 ± 9.85	2079.23 ± 108	1.8 ± 0.00	
	2	2.14 ± 0.16	30.26 ± 10.48	1994.67 ± 108	1.7 ± 0.07	
	4	8.05 ± 1.16	29.77 ± 7.27	2241.07 ± 654	1.7 ± 0.02	
	6	44.43 ± 1.66	27.00 ± 6.38	1811.12 ± 210	1.8 ± 0.02	
LSD (< 0.05)		3.985	ns	ns	ns	
Grain						
0	0	N.D.*	15.46 ± 9.03	4019.60 ± 313	0.64 ± 0.01	1.66 ± 0.14
	1	3.96 ± 0.12	23.10 ± 3.16	6057.23 ± 884	0.57 ± 0.01	1.48 ± 0.07
	2	4.15 ± 0.07	19.47 ± 4.98	6322.50 ± 0	0.59 ± 0.01	1.42 ± 0.04
	4	4.34 ± 0.09	15.17 ± 3.32	5040.31 ± 221	0.58 ± 0.01	1.45 ± 0.03
	6	4.58 ± 0.52	18.41 ± 4.76	5438.68 ± 158	0.56 ± 0.01	1.21 ± 0.00
1.5	0	N.D.	32.73 ± 6.34	6189.86 ± 159	0.57 ± 0.02	1.42 ± 0.05
	1	8.07 ± 0.35	46.24 ± 21.9	5239.28 ± 420	0.56 ± 0.01	1.43 ± 0.07
	2	8.01 ± 0.04	37.39 ± 6.40	3979.19 ± 1371	0.60 ± 0.05	1.22 ± 0.15
	4	7.92 ± 0.17	16.73 ± 8.88	6631.99 ± 0	0.60 ± 0.01	1.66 ± 0.00
	6	8.07 ± 0.07	17.06 ± 8.85	6013.01 ± 0	0.58 ± 0.01	1.35 ± 0.10
3.0	0	N.D.	29.29 ± 3.36	4730.83 ± 88	0.57 ± 0.02	1.45 ± 0.22
	1	3.87 ± 0.05	29.09 ± 9.67	4509.76 ± 0	0.58 ± 0.02	1.29 ± 0.01
	2	8.05 ± 0.33	42.29 ± 19.85	5040.32 ± 619	0.57 ± 0.01	1.44 ± 0.08
	4	7.55 ± 0.03	25.22 ± 10.54	4465.55 ± 884	0.60 ± 0.04	1.71 ± 0.69
	6	7.46 ± 0.13	17.94 ± 1.68	5850.89 ± 443	0.57 ± 0.01	1.42 ± 0.07
LSD (< 0.05)		0.3293	ns	903.5	0.0349	ns

*ND = could not be determined (below the detection limit); **ns = not significant.

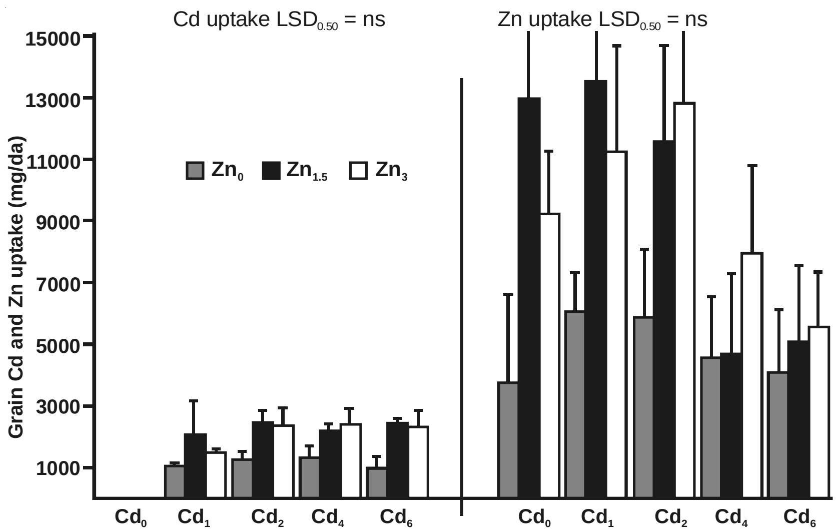

Fig. 2. Effect of different doses of Cd and Zn application on grain Cd and Zn content. Error bars represent ± SE of triplication (n = 3)

TABLE-2
FLAG Cd/GRAIN Cd RATIO OF TRITICALE GROWN UNDER FIELD CONDITIONS (n = 3)

Zn dose (kg/da)	Cd dose (kg/da)	Flag Cd/grain Cd ratio
0	0	0.0 g
	1	0.130 g
	2	0.433 efg
	4	0.860 def
	6	1.110 d
1.5	0	0.0 g
	1	0.587 defg
	2	1.047 de
	4	4.063 c
	6	4.980 b
3.0	0	0.0 g
	1	1.027 de
	2	0.267 fg
	4	1.067 de
	6	5.960 a
$LSD_{0.50}$		0.6522

Flag Cd/grain Cd ratio: This rate showed an increase with increased doses of both zinc and cadmium and these increases were found statistically significant ($p < 0.05$). It was also observed that the amount of Cd transferred from the leaves to the grain was high in Zn_0 application; but at increased doses of Zn, although the amount of cadmium applied increased, the cadmium accumulation in the grain showed a decrease (Table-2).

As shown from obtained results, increasing Zn application rate (from 0 to 3 kg da^{-1}) increased firstly the Cd concentration in grains of triticale (synergistic effect) but latter decreased (antagonistic effect) under field conditions. Cadmium concentration exceeded the maximum permissible concentration (0.05 mg/kg) in grain even at the lowest Cd application.

The results have emphasized that the selection of the application Zn fertilizer *via* soil or foliar; using the low-Cd P fertilizers; the most appropriate triticale genotypes with low capacity to take up and accumulate Cd in grain. In addition, it may be possible to predict the Cd concentration in grain by analysing the Cd concentration in shoots early in the season. Hence it can be eliminate the health and environmental risks posed by Cd accumulation in grains of cereals can be eliminated. Further studies are needed to select triticale genotypes with low capacity to take up and accumulate Cd in grain.

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