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INTERACTION BETWEEN CADMIUM AND ZINC IN BARLEY (*HORDEUM VULGARE* L.) GROWN UNDER FIELD CONDITIONS

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Abstract

The interaction between cadmium (0, 1, 2, 4 and 6 kg/da) and zinc (0, 1.5 and 3 kg/da) in barley (*Hordium vulgare* L. cv. Karatay-94) alone and in combination at tillering stage (3 - 4 leaf) grown under field conditions showed no phytotoxic symptoms. Cd application did not affect the grain yield of barley. Cd concentrations in flag leaf and grain increased marginally with increasing level of Cd but decreased with increasing Zn application. Cd and Zn application caused insignificant changes in N and K concentrations in barley. But P concentration in grain at especially Zn_0 dose decreased with increasing level of Cd application. The effect of different doses of Cd and Zn on grains Cd content was found to be significant. Increased Cd doses generally decreased Zn content in grains.

Introduction

The Cd content of agricultural soils and crops in Turkey has attracted attention in the last few decades as a result of a growing awareness about environmental and food quality issues among both producers and consumers. Nutrient deficient agricultural soils in Turkey have been remediated especially through the application of fertilizers containing NPK. Koleli and Kantar (2005) studied Cd concentration in phosphate rock, phosphoric acid and phosphorous fertilizers in Turkey and reported that it was above the standard value of 8 mg/kg fertilizer in 10 out of total 14 fertilizers analyzed. Thereby, commercial fertilizers are considered to be a major source of Cd in agricultural soils of Turkey.

Many reports have shown that the use of Cd-containing fertilizers increased Cd uptake by plants (Anderson and Simon 1991). The current widespread interest to Cd uptake and translocation in plants arises from the incidence of harmful health effects of its dietary intake. High retention of Cd in roots is particularly desirable in forage, cereal and vegetable crops where the roots are not utilized, thus reducing Cd burdens to animal and man. But there is much evidence that Cd may accumulate in cereal grains (Oliver *et al.* 1994, Köleli *et al.* 1998, Nan *et al.* 2002).

In Turkey, 50% of arable soils are zinc deficient (Cakmak *et al.* 1999). The Zn removed by crops is usually not fully replenished by fertilization in agricultural soils. Zinc deficiency in soils may enhance Cd absorption and transport in crop plants. Due to chemical similarity between Cd and Zn, many studies have been conducted to establish the existence of Cd-Zn interaction in soil-plant systems (Abdel-Sabour *et al.* 1988, Das *et al.* 1997, Nan *et al*. 2002). Interactions of Cd-Zn and their accumulation in plant in solution culture or in pot experiment have been reported (Coughtrey and Martin 1979, Abdel-Sabour *et al.* 1988, Smilde *et al.* 1992, Moroghan 1993, McKenna *et al.* 1993, Dudka *et al.* 1994, Zhou *et al.* 1994, Koleli *et al.* 2004). However, there is scanty information about the interactions between Cd and Zn in barley under field conditions. The present field study was conducted to examine the nature of the interaction between Cd and Zn in barley since after wheat it is a major crop in Turkey.

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Materials and Methods

The field experiment was conducted on barley (*Hordeum vulgare* L. cv. Karatay-94) in the farm of Konya Agricultural Research Institute located in the central Anatolia of Turkey. The mean annual precipitation, humidity and temperature were 350 mm, 55.2% and 12.2^{o} C, respectively. This region is considered to be important for the production of most of the cereal crops.

Soil sample was collected from 0 - 20 cm depth, dried in air, sieved through a 2 mm screen, and mixed well before subsampling. The samples were analyzed for pH and electrical conductivity at a soil : water ratio being 1 : 2.5; textural class, organic matter (Smith and Weldon 1941); available P (Olsen *et al*. 1954), water-soluble K by Flamephotometer (Bayrakli 1986), and calcium carbonate by Scheibler calcimeter method as described by Jackson (1958). Total soluble salt content was calculated from the value of electrical conductivity. Particle-size was analyzed by the Bouyoucous hydrometer method (Anonymous 1951). DTPA-extractable Cd and Zn were analyzed according to procedure outlined by Lindsay and Norvell (1978).

Planting was done on 15^{th} of October. All treatments were replicated three times in a randomized block design. The treatments were triplicated on 3 × 3 m plots separated by 1.5 m intervals within rows. N and P fertilizers in the form of DAP at 10 kg/da were applied during planting and NH_4NO_3 at 5.6 kg/da was applied to ensure proper growth of barley about four months after planting. 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) and three levels of Zn as $ZnSO_4.7H_2O$ (0.0 (Zn_0), 1.5 ($Zn_{1.5}$) and 3.0 (Zn_3) kg Zn/da) were applied by a pulverizator during tillering stage and were applied at one week interval, respectively.

Plant growth parameters (e.g. emergence, flowering, heading, plant height and head height) were recorded during the experiment. Flag leaf and grain samples were taken at heading stage and at maturity, respectively. Grain samples were taken after eight months from planting. At the end of the experiment, samples of flag leaves and grain were dried at 70^{o} C and grounded. Dried plant samples were digested using a H_2SO_4 and H_2O_2 mixture (Bayraklı 1986). Aliquots were diluted and analyzed for Cd and Zn using Inductively Coupled Plasma Atomic Emission Spectrophotometer (Varian Vista AX ICP-AES). The detection limit for both Cd and Zn was 0.3 µg/l. Samples were also analyzed for phosphorous, nitrogen and potassium, except nitrogen in flag leaves.

All data were analyzed using the statistical package GENSTAT and MSTAT programs. LSD was calculated to compare the main treatment and interaction effects at $p < 0.05$.

Results and Discussion

Initial soil pH, EC, textural class, organic matter, available P_2O_5, soluble K_2O, DTPA-extractable Zn, DTPA-extractable Cd and free carbonate were found 7.9 (alkaline), 0.34 mmhos/cm, sandy loam, 1.03 %, 6.41, 108.45, 0.64 mg/kg below the detection limit, and 12.87%, respectively.

During the experiment, crop growth parameters were recorded. Since the statistical analysis showed that the effect of Cd and Zn on plant height, head height and 1000-grain weight was not significant, these data were not included. No phytotoxic symptoms were detected during the experiment.

Grain yield was not significantly affected by foliar application of Cd and Zn alone, and Cd-Zn interaction (Fig. 1). Zn_1 and Zn_2 treatments increased the grain yield of barley 44 and up to 52%, respectively over Cd_0-Zn_0 treatment. Zn_0, $Zn_{1.5}$ and Zn_3 application at Cd_1 doses, in contrast to Cd_0, increased grain yields by about 23, 52 and 50%, respectively. Maximum grain yield was obtained at Cd_2-Zn_3 treatment (351 kg/da). Yield obtained at this dose was 53% higher than Cd_0-Zn_0

treatment. Similar results were reported by Koleli (1998) for cereals and by Smilde *et al.* (1992) for spinach. Results obtained for grain yield were similar to 1000 grain weight (data not shown).

The effect of foliar-application of Cd and Zn on Cd, Zn, N, P and K concentrations are shown separately for flag leaf and grain in Table 1. Critical concentration of Cd for barley was 14 - 15 mg/kg (Smith 1996). Except in Cd_6 - Zn_3 dose (20.5 mg/kg), flag leaf analysis showed that Cd and Zn concentrations were below the levels causing toxicity symptoms (Bingham *et al.* 1975). Added Zn increased significantly Zn concentration of flag leaf. However, applied Zn also increased Zn concentration of grain but this effect was not significant. These effects were slightly enhanced by applied Cd. These synergistic effects were obtained especially in grain at Zn_1 - Cd_3 and $Zn_{1.5}$ - Cd_4 doses. Application of Cd increased flag leaf and grain Cd concentration of barley.

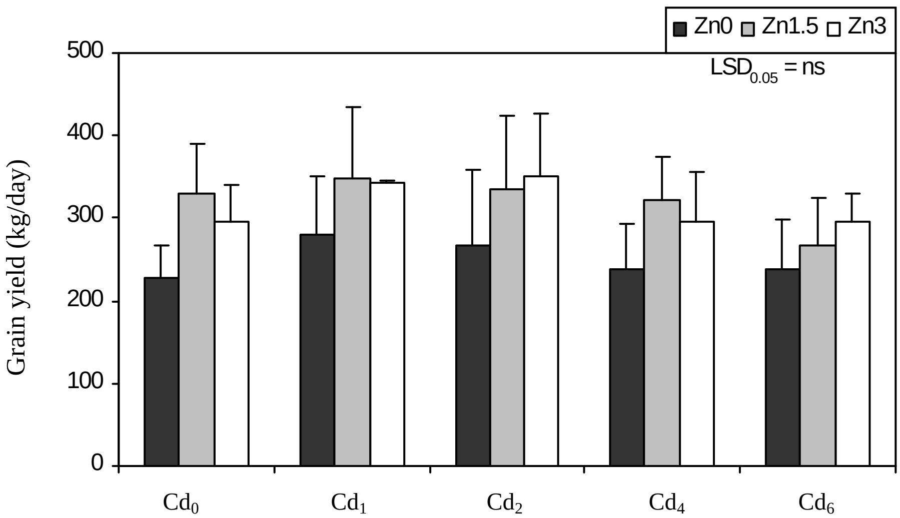

Fig. 1. Effect of different doses of Cd and Zn on grain yield of barley. Error bars represent ± SE of triplication (n = 3).

The effect was synergistic at $Zn_{1.5}$ and antagonistic at Zn_3. Flag leaf Cd concentration increased with level of Cd (Table 1). The highest Cd concentration (14.97 mg/kg) was recorded in 4 kg Cd/day treatment. Wu *et al.* (2003) reported that kernel Cd concentrations of four barley genotypes grown in Cd treated soil was different among genotypes and changed from 4.04 to 6.16 mg/kg DW at maximum Cd doses. On the other hand, leaf Cd concentration increased with added Zn but the result was not significant. The flag leaf Cd concentration increased with 1.5 kg Zn/da but decreased at 3 kg Zn/da treatment. This means Cd uptake was prevented by Zn treatments. Added Zn significantly increased Zn concentration of flag leaf ($p < 0.05$). Zinc application did not increase grain Zn concentration. Wu *et al.* (2003) conducted a hydroponic experiment in greenhouse to study the interaction of Cd with Zn, Cu, Fe and Mn on accumulation and distribution Zn in barley during ontogenesis and their difference among genotypes and reported that Cd addition significantly decreased Zn concentration in all plant tissues. Similar data were also reported by Moroghan (1993) in flax seed under field conditions. Cadmium accumulation in grain under Zn-deficient conditions was recorded by other investigators (Moroghan 1993, Oliver *et al.* 1994, Grant and Bailey 1998) and Zn-deficiency enhance phloem-mediates transport of Cd to grains (Cakmak *et al.* 2000). Zn application usually inhibits Cd accumulation due to the Cd-Zn competition.

The interference of Cd and Zn with a number of physiological processes possibly associated with normal growth and development in plants (Woolhouse 1983, Van Assche and Clijsters1990). Peterson (1977) reported that Cd uptake by several barley varieties were not significantly different. Wu and Zhang (2002) found that increasing Zn application could alleviate Cd toxicity stress in barley by improving growth and reducing membrane damage.

Table 1. Effect of Zn and Cd on Cd, Zn, N, P and K accumulation in grain and flag leaves of barley grown under field conditions.

Zn dose (kg/day)	Cd dose (kg/day)	Cd (mg/kg DW)	Zn (mg/kg DW)	P (mg/kg DW)	K (%)	N (%)
Flag leaf						
0	0	ND	15	2231	1.8	-
	1	4.5	12	1746	1.7	-
	2	7.8	11	2276	1.9	-
	4	9.6	12	2276	1.7	-
	6	12.9	11	2171	1.8	-
1.5	0	ND	21	2147	1.8	-
	1	10.2	17	2605	1.8	-
	2	10.0	17	2335	1.9	-
	4	14.7	16	1807	1.6	-
	6	20.5	25	2241	1.8	-
3	0	ND			1.9	-
	1	4.5	22	2452	1.9	-
	2	4.5	15	2370	1.9	-
	4	4.5	30	2499	1.8	-
	6	5.5	21	2229	1.9	-
LSD (< 0.05)		2.35	6.43	ns	ns	
Grain						
0	0	ND*	20	5477	0.50	1.6
	1	3.5	25	5992	0.58	1.3
	2	6.5	25	4967	0.54	1.4
	4	7.4	24	3011	0.56	1.4
	6	12.0	23	1696	0.55	1.5
1.5	0	ND				
	1	9.3	23	3942	0.59	1.4
	2	9.8	23	4652	0.58	1.3
	4	10.3	22	4775	0.59	1.4
	6	12.3	22	4264	0.57	1.6
3	0	ND	50	5813	0.57	1.4
	1	8.4	30	5593	0.56	1.3
	2	7.9	31	5790	0.55	1.5
	4	5.7	31	4604	0.57	1.3
	6	4.0	31	4332	0.56	1.2
LSD (< 0.05)		0.91	8.82	1976	ns	ns

ND = Not determined (below the detection limit); ns = Non significant.

Cd and Zn application did not change N and K concentrations in flag leaf and grain markedly (Table 1). But P concentration in grain especially at Zn_0 dose significantly decreased with increased Cd application (Table 1).

The effects of different doses of Cd and Zn on grain Cd and Zn uptake were shown in Fig. 2. At Zn_0 and $Zn_{1.5}$ doses, grain Cd uptake increased with increased Cd application. But grain Cd uptake at Zn_3 treatment decreased appreciably. The effect of different doses of Cd and Zn on grain Cd content was found to be statistically significant (Fig. 2). Zinc application increased Zn uptake in grain as expected. This increment was maximum in absence of Cd. But increased Cd doses decreased Zn uptake in grain. The highest Zn content in grain was 17256 mg/da at Cd_0-Zn_3 doses. These results imply that while low level Cd enhanced Zn uptake and high level of Cd inhibits Zn uptake in barley grain.

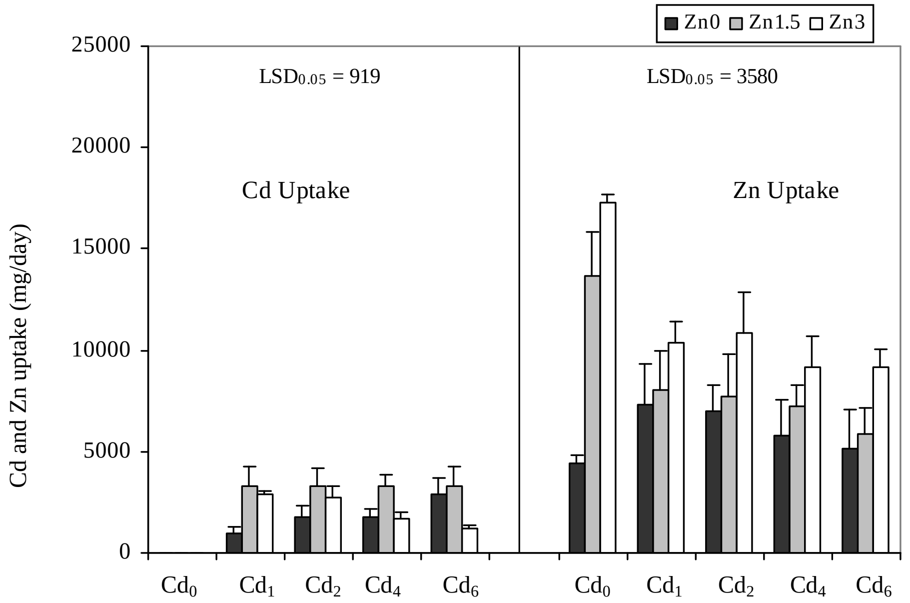

Fig. 2. Effect of different doses of Cd and Zn on Cd and Zn uptake by barley grain. Error bars represent ± SE of triplication (n = 3).

Results showed that increase in rate of Zn application (from 0 to 3 kg/da) increased firstly the Cd concentration in grains of barley (synergistic effect) but later decreased (antagonistic effect) under field conditions. Cadmium concentration exceeded the maximum permissible concentration (0.05 mg/kg) in grain even at the lowest rate of Cd application.

The results have emphasized the selection of the most appropriate barley 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 analyzing the Cd concentration in shoots early in the season to eliminate the health and environmental risks posed by Cd accumulation in grains of cereals. However, further studies are needed to select the appropriate barley genotypes.

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References

Abdel-Sabour, M.F. , J.J.Mordvedt and J.J.Kelsoe.1988.Cd-Zn interactions in plants and extractable Cd and Zn fractions in soil. Soil Sci. **145**: 424-431.

Anderson, A. and G. Simon. 1991. Levels of Cd and some other trace elements in soils and crops as influenced by lime and fertilizer level. Acta Agric. Scand. **41**: 3-11.

Bayraklı, F. 1986. Soil and plant analyses Ondokuz Mayıs Univ. Agricultural Faculty.

Bingham, F.T., A.L.Page, R.J.Mahler and T.J.Ganje.1975. Growth and cadmium accumulation of plants grown on a soil treated with cadmium-enriched sewage sludge. J. Environ. Qual. **4**: 207-211.

Cakmak, I., M. Kalayci, H. Ekiz, H.J. Bruan, Y.Kiline and A. Yilmaz.1999. Zinc deficiency as practical problem in plant and human nutrition in Turkey: A NATO-science for stability project. Field Crops Res. **60**: 175-188.

Cakmak, I. ,R.M.Welch, B.Erenoglu, V.Romheld, W.A. Norvell and L.V. Kochian. 2000. Influence of varied zinc supply on re-translocation of cadmium (^{109}Cd) and rubidium (^{86}Rb) applied on mature leaf of durum wheat seedlings. Plant and Soil. **219**: 279-284.

Coughtrey, P.J. and M.H. Martin.1979. Cadmium, lead and zinc interactions and tolerance in two populations of *Holcus lanatus* L. grown in solution culture. Environ. Exp. Bot. **19**: 285-290.

Das, P, S.Samantaray and G.R. Rout. 1997. Studies on cadmium toxicity in plants:a review. Environ Pollut. **98**: 29-36.

Dudka, S, M.Piotrowska and A. Chlopecka. 1994. Effect of elevated concentrations of Cd and Zn in soil on spring wheat yield and the metal contents of the plants. Water Air Soil Pollut. **76**: 333-341.

Grant, C.A. and L.D. Bailey . 1998. Nitrogen, phosphorus and zinc management effects on grain yield and cadmium concentration in two cultivars of durum wheat. Canad. J. Plant Sci. **78**(1): 63-70.

Koleli, N. 1998. The effect of zinc deficiency on tolerance to cadmium toxicity in different cereal species and wheat cultivars. Ph. D. Thesis, Agricultural Engineering Faculty, Dept. Soil Science, Çukurova Univ., Adana, Turkey.

Koleli, N., Ö. Çakmak, F. İşler and I. Çakmak. 1998. The effects of zinc nutrition on cadmium toxicity in different cereal species. I. National Zinc Congress (Agriculture, Food and Health) pp.491-500.

Koleli, N., S. Eker and I. Cakmak. 2004. Effect of zinc supply on cadmium toxicity in durum and bread wheat grown in zinc-deficient soil. Environ. Pollut. **131**: 453-459.

Koleli, N. and Ç. Kantar. 2005. Toxic heavy metal (Cd, Pb, Ni, As) concentrations in phosphate rocks, phosphoric acids and phosphorus fertilizers. Ekoloji Dergisi. **55**: 1-5.

Lindsay, W.L. and W.A. Norvell . 1978. Development of a DTPA soil test for Zn, Fe, Mn and Cu. Soil Sci. Soc. Amer. Proc. **42**: 421-428.

Jackson, M.L.1958. Soil Chemical Analysis.Prentice - Hall, Inc. Englewood Cliffs, N.J.

Jarvis, S.C., H.P. Jones and M.J. Hopper .1976. Cadmium uptake from solution by plants and its transport from roots to shoots. Plant and Soil **44**: 179-191.

McKenna, I.M., R.L.Chaney and F.M. Williams.1993. The effects of cadmium and zinc interaction on the accumulation and tissue distribution of zinc and cadmium in lettuce and spinach. Environ. Pollut. **79**: 113-120.

Moroghan, J.T.1993. Accumulation of cadmium and selected elements in flax seed grown on a calcareous soil. Plant and Soil **150**: 61-68.

Nan, Z.R., J.J.Li , J.M. Zhang and G.D. Cheng. 2002. Cadmium and zinc interactions and their transfer in soil-plant system under actual field conditions. Sci. Total Environ. **285**: 187-195.

Oliver, D.P., R.Hannam , K.G. Tiller and N.S. Wilhelm. 1994. The effects of zinc fertilization on cadmium concentration in wheat grain. J. Environ. Qual. **23**: 705-711.

Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. **939**.

Petterson, O. 1977. Differences in cadmium uptake between plant species and cultivars. Swed. J. Agric. Res. **7**: 21-24.

Smilde, K.W., B.Van Luit and W. Van Driel. 1992. The extraction by soil and absorption by plants of applied zinc and cadmium. Plant and Soil **143**: 233-238.

Smith, H.W. and M.D. Weldon. 1941. A comparison of some methods for the determination of soil organic matter. Soil Sci. Soc. Amer. Proc. **5**: 177-182.

Smith, S.R. 1996. Agricultural Recyling of Sewage Sludge and the Environment. C A B Intl. Published, Great Britain.

Anonymous. 1951. Soil Survay Manual, U.S. D.A. Handbook. **18**: 235.

Sterckeman, T., F. Douay, N. Proix and H. Fourrier. 2000. Vertical distribution of Cd, Pb, and Zn in soils near smelters in the north of France. Environ Pollut. **107**: 377-389.

Van Assche, F. and H. Clijsters. 1990. Effects of metals on enzyme activity in plants. Plant Cell Environ. **13**: 195-206.

Woolhouse, H.M. 1983.Toxicity and tolerance in the responses of plants to metals. in O. L.Lange, P. S. Nobel, C. B. Osmond and H. Ziegler (Eds), Encycl. Plant Physiol., Springer Verlag, Berlin, pp. 245-262.

Wu, F.B. and G.P. Zhang. 2002. Alleviation of cadmium-toxicity by application of zinc and ascorbic acid in barley. J. Plant Nutr. **25**: 2745-2761.

Wu, F.B, G.P. Zhang and J. Yu. 2003. Interaction of cadmium and four microelements for uptake and translocation in different barley genotypes. Commun. Soil Sci. Plant Analysis **34**(13&14): 2003-2020.

Zhou, Q., Y.Wu and X. Xiong. 1994. Compound pollution of Cd and Zn and its ecological effect on rice plant. Chin. J. Appl. Ecol. **5**: 428-441 [in Chinese].

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