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Research Article

Cadmium Pollution Impairs Maize Growth and Uptake of Cationic Essential Nutrients

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Abstract

Human population is anticipated to increase to 9.8 billion by 2050 and this increase causes a more intensive agricultural production. The soils are polluted as the farming activities are intensified. Fertilizers and the pesticides that are used in agriculture and the imbalanced industrialization cause heavy metals to move into the soil thereby creating soil-environmental pollution. Cadmium (Cd), one of the heavy metals, is also present in the biosphere, enters the soil as a result of natural processes and anthropogenic activities, exerting toxic effects on agricultural products, food chain and living organisms. This highly toxic and dangerous metal has come to the fore with its important role in environmental pollution due to its various usage areas. In this study, the effects of three different Cd doses on the cationic macro and micronutrient content of maize plant was investigated. Cadmium application at 2.5 and 5.0 mg kg^{-1} decreased shoot dry matter by %10.8 and %20.0 respectively compared with control treatment. While the highest macro and micronutrient contents were obtained in the control treatment, the lowest values were obtained in the Cd5 treatment. Cadmium applications were not statistically significant in shoot K, Mg and Ca concentrations but significantly decreased K and Ca contents. Compared with the control treatment, Cd applications at 2.5 and 5.0 mg/kg were determined to decrease the K content by % 9.9 and % 18.4 and Ca content by 17.7% and 21.3% respectively. When the Cd concentration and content are determined, the highest values were found to be in the Cd5 treatment. Consequently, increased Cd accumulation in shoots was determined to be associated with decreases in K, Ca, Cu, Zn, Fe and Mn uptake of maize plant. Therefore, close monitoring of nutritional problems that can potentially occur in agricultural areas contaminated with Cd might be beneficial for the evaluation of different solution proposals

Keywords
Cadmium, Macro nutrient, micronutrient, nutrient content, nutrient concentration

INTRODUCTION

The human population has been increasing rapidly and it has grown from 250 million in the year 1000 to 6.1 billion in the year 2000 and is anticipated to increase to 9.8 billion by the year 2050 (Kopittke et al., 2019). Due to the food demand created by the population increase, the need for more agricultural production and yield per unit area has arisen. Presently, agriculture is the main source of economy in most developing countries and 42% of population worldwide rely on agriculture for its subsistence. Hence, human life on our planet is dependent on the sustainability (Aznar-Sanchez et al., 2019) and manageability of agriculture. Unfortunately, the desire to obtain more crops per unit area places a great pressure on soils both in terms of physical and quality degradation. As farming activities are intensified, the lands are also polluted and eventually become unsuable**.** The fertilizers and pesticides used in agriculture contain heavy metals at certain levels (Sönmez et al., 2008) and these heavy metals are one of the most important factors that can cause soil pollution. Plants are considered staple food for human nutrition therefore plant nutrition is of vital importance. Plants absorb at least 20 nutrients which are classified as macro and micro nutrients from soil, water and air in order to grow and develop (Bolat and Kara, 2017). Also, these nutrients are taken up in anion and cation forms. In addition to the aforementioned nutrients, plants easily take up heavy metals too. The heavy metals are defined as metals with a density of more than 5 g/cm^3 and an atomic weight of 50 or > 50 (Dağhan, 2011). The most common metal pollutants in soils consist of about 60 metals, including lead (Pb), mercury (Hg), arsenic (As), chromium (Cr), copper (Cu), nickel (Ni) and cadmium (Cd) (Dağhan et al., 2013). The transfer of heavy metals to the soils via fertilization is mostly caused by phosphorus-based fertilizer applications (Sönmez et al., 2008). Plants easily assimilate heavy metals (e.g., Zn, Cd, Ni, Cu, Hg) (Foy et al., 1978; Lepp, 1981). Heavy metals are strong phytotoxics that cause plant death (Clijsters and Van Assche, 1985). Due to excessive accumulation of cationic heavy metals such as Cd+2, Pb+2 ve Ni+2, plant resistance decreases thereby affecting the vegetative and generative organs of plants as well as all living organisms in nature (Okcu et al., 2009) and these metals function as factors that cause physiological restrictions (Clijsters and Van Assche, 1985; Ouzounidou, 1993; Påhlsson, 1989; Van Assche and Clijsters, 1990). Cadmium, a heavy metal which is also present in the biosphere, enters soils as a result of natural processes and anthropogenic activities (Fan et al., 2009), exerts toxic effects on agricultural products (Rafique et al., 2019), food chain (Jan et al., 2020) and living organisms (Erdoğrul et al., 2005). Furthermore, it is a highly toxic (Abbas et al., 2017) and dangerous metal which has become a current issue due to its significant role in environmental pollution and various usage areas (Çelim, 2018; Asri et al., 2007; Sozubek et al., 2014; Zhong et al., 2012; Sarwar et al., 2015; Sarwar et al., 2010). Cadmium which is an extremely mobile element in the soil, can be easily taken up by plants. Although cadmium is not essential for plants, it enters the food chain through its uptake by plants and creates an environmental problem by being leached away from the soil and eventually reaching the water resources (Zhu et al., 2003; Asri et al., 2007). Cd content in plants is generally less than 0.5 mg/kg on a dry weight basis. It varies greatly depending on the plant genus and species. While peas, potatoes, beans, cabbage and vegetables generally contain low amounts, high levels of Cd are found in celery, green cabbage, spinach and leaf lettuce (Özbek et al., 1995). Cadmium reduces water and ion uptake of plants because it inhibits plant root growth and development. Excessive amount of Cd reduces the uptake of macro and micronutrients by plants, thereby impairing food quality (Rochayati et al., 2011). Hernández et al. (1998) reported that with increasing Cd doses, Mn and Fe concentration in roots and shoots of pea plants decreased by 70% and 77% respectively compared to the control treatment and that this is due to the fact that Cd disrupts the integrity and permeability of the plasma membrane through changes in the functions of nutrient transporters and Mg+2-ATPases. Sozubek et al. (2014), carried out research to investigate the effects of cadmium pollution on maize plant which is used in the selection of raw material in the industry for human nutrition and animal feed and is the most widely grown cereal in the last decade. They reported that increasing doses of Cd and Zn applications rise Cd accumulation in plant shoots and roots and as soils are contaminated with Cd, it will eventually end up in human and animals via maize consumption. The present study was designed and conducted based on the above-mentioned information. We hypothesized that increasing Cd doses decreases cationic macro and micronutrients uptake by plants thereby declining plant root and shoot biomass. The objectives of this study were to test the effect of increasing concentration of Cd on plant cationic micro and macronutrient uptake.

MATERIAL and METHODS

The present study was conducted in a greenhouse of Çukurova University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition between 25th March 2019 and 26th April 2019. The soil used in the present study is locally named as Arık and basic physiochemical properties of the experimental soil are provided in Table 1. A commercially available and widely grown maize cultivar (Pioneer-Hektaş) was used as the plant material. The experiment was carried out in pots containing 2 kg soil with 4 maize seeds sown in each. Ten days after planting, the seedlings were thinned to 2 plants.pot^{-1}. The experimental design employed was randomized complete plot design (RCPD) with four replicates. The following nutrient (mg.kg^{-1}) rates were applied as basal fertilization: 200 N (as Ca $(NO_3)2$), 100 P (as $CaH_4O_8P_2H_2O$), 50 K (as K_2SO_4), 2 Zn (as $ZnSO_4.7H_2O$) and 2 Fe (as Fe-EDTA). The cadmium source $3(CdSO_4).8H_2O$ was applied in increasing application rates of 0%, 2.5% and 5.0%. Deionized water was used throughout the experiment. At the end of experiment, the shoots (above-ground) and roots were harvested together, Thereafter, the harvested parts were cautiously washed with distilled water to remove soil, their fresh weight was recorded and placed in kraft paper bags. The bags containing plants and roots were then placed in the oven and dried at 70 ° for 48 hours. Next, shoot and root dry weights were recorded, then plants were ground and dry-ashed and samples were made ready for analysis. Ultimately, the K, Ca, Mg, Fe, Mn, Zn and Cu concentrations in the samples were determined using an atomic absorption spectrophotometer device (Thermo ICE 3000 series) (Kacar and İnal, 2008) and the contents were calculated (concentration *shoot dry weight (g.plant^{-1})**.** Some physical and chemical properties of the trial soil were determined according to standard soil analysis methods (Kacar, 2009).

Table 1. Physicochemical properties of the soil used in the experiment

pH	Texture	EC dS m^{-1}	$CaCO_3$	OM	N	P	K	Fe	Mn	Zn	Cu
			%					mg kg^{-1}			
7.60	Silty Loam	0.241	29.08	1.29	0.124	0.00106	0.036	2.93	8.81	0.54	1.59

RESULTS and DISCUSSIONS

According to data present in figure 1, while the effect of cadmium treatment rates, on root dry weight was not found to be significant, the increasing cadmium doses was found to decrease shoot dry weight and this decline was determined to be statistically significant at p<0,01. In this context, the plant dry weights for Cd0, Cd2,5 and Cd5 were recorded to be 1511 mg. $plant^{-1}$, 1346 mg. $plant^{-1}$ and 1208 mg. $plant^{-1}$ respectively.

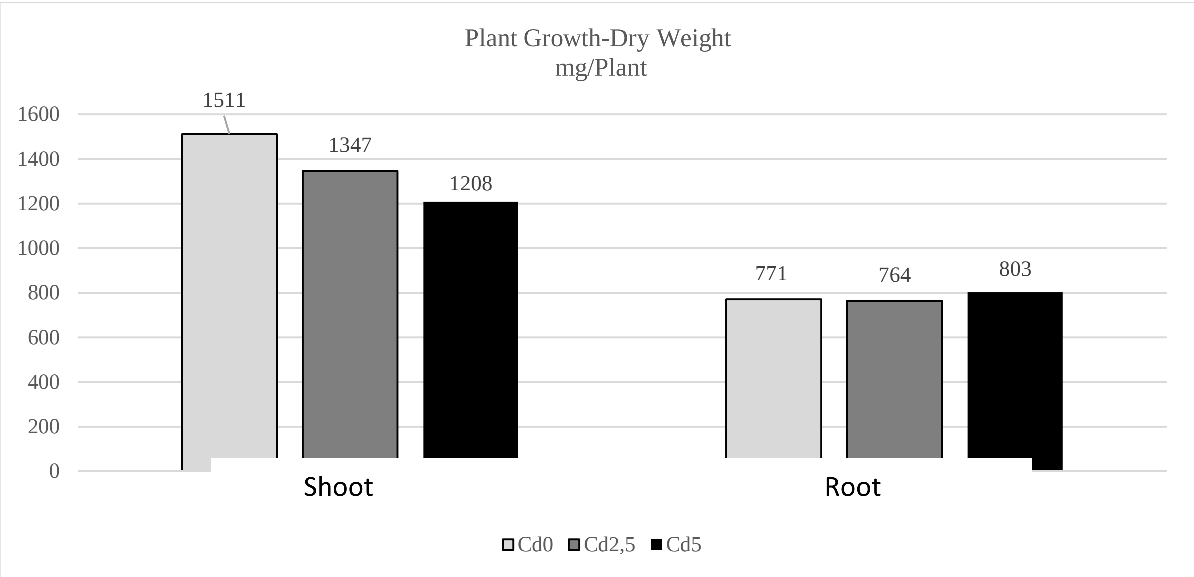

Figure 1. Effect of different Cd doses on the shoot and root dry weight of maize plant.

These values are in accord with other works reported in the literature. Asri et al. (2007) suggests that cadmium accumulation in plants decreases yield and quality thus it causes a significant yield loss. Sikka and Nayyar (2012) reported a decline in dry matter yield of Indian mustard with increasing Cd doses in the soil. Shen et al. (2006) stated that they observed a significant decrease in root biomass of maize plant with the addition of increasing amounts of Cd. As a result of excessive accumulation of cationic heavy metals such as Cd+2, Pb+2 and Ni+2 in plants, plant resistance is weakened and these cationic heavy metals act as factors that cause physiological restrictions on plant growth.
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(Clijsters and Van Assche, 1985; Ouzounidou, 1993; Påhlsson, 1989; Van Assche and Clijsters, 1990). Excessive Cd application reduces wheat growth, biomass, photosynthesis activity, and grain yield and hampers mineral nutrition (Rizwan et al., 2016; Rehman et al., 2015).. In an experiment aimed at determining the toxic threshold values of the wheat plant, Kalınbacak et al. (2012) revealed that wheat dry weight and yield decreased with increasing Cd concentration, that the highest wheat dry weight was obtained in the control treatment and that the increments in soil Cd concentration increased the plant Cd content

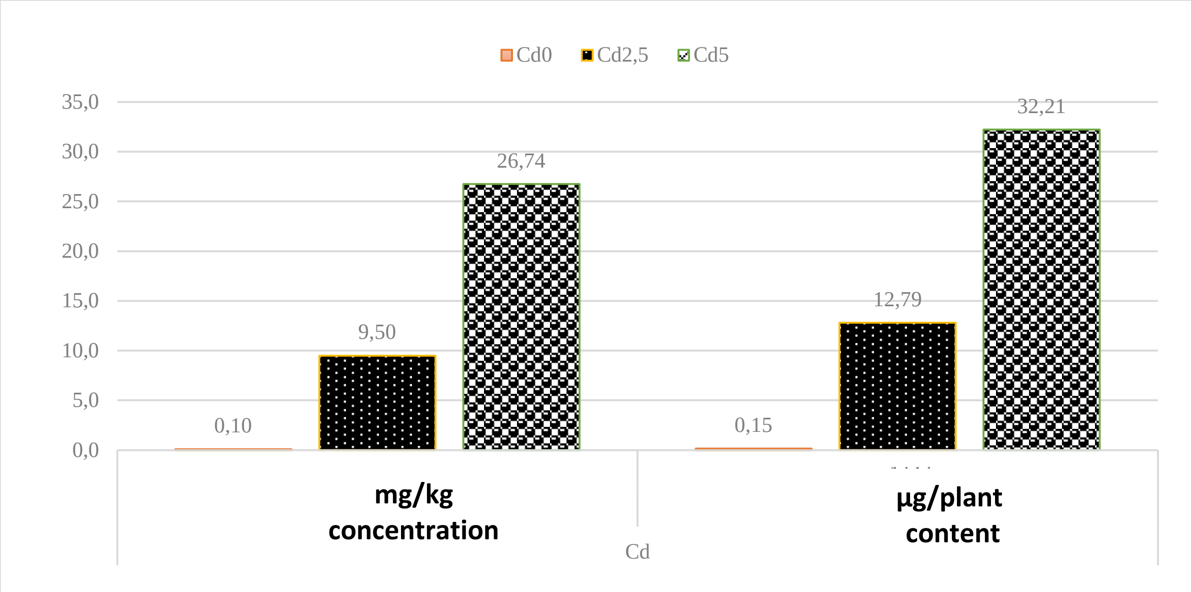

Figure 2. The effect of different Cd doses on the Cd concentration and content of the maize plant

The application of Cd in increasing doses resulted in increments of Cd concentration and content in the maize plant tissue and this increase was statistically significant at p<0,01 (Figure 2). The highest Cd concentration and content values were obtained at the Cd 5 treatment dose and these values were 26.74 mg/kg and 32.21 mg/kg, respectively. Kalınbacak et al. (2012) reported that the Cd content in the above-ground biomass of wheat increased with increments in Cd doses applied to the soil. Abbas et al. (2017) stated that Cd concentration in plant tissues was positively correlated with soil Cd values and that Cd could enter plant cells specifically through the uptake system of and of essential nutrients in general. Therefore, they suggested that Cd uptake could be reduced compared to the control plant through biochar application to the soil and by having sufficient amounts of Zn and Mn in the soil. (Sozubek et al., 2014) reported that, with increasing doses of Cd and Zn applied to the maize plant, the Cd concentration in the plant increased and this increase led to the accumulation of Cd in the shoots and roots. Also, a positive correlation between the Cd amounts in the soil and the Cd concentration in the plants was recorded.

Table 2. Effects of different Cd doses on cationic microelement concentration and content of maize plant

Treatments	Concentration				Content			
	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn
	mg/kg				µg/plant			
Cd0	11.03	33.15	110.56	57.56	16.66 a	50.19 a	167.02 a	86.61 a
Cd2,5	10.07	34.27	103.97	58.55	13.59 b	46.16 a	140.04 b	78.89 b
Cd5	10.06	31.29	102.35	56.78	12.13 b	37.54 b	122.99 b	68.39 c
P	P= 0.1602	P=0.2054	P= 0.4528	P= 0.7703	P= 0.0068**	P= 0.0038**	P= 0.0106**	P= 0.0013**

**significant at 1%

Table 3. Effect of different Cd doses on cationic macro element concentration and content of maize plant

Treatments	Concentration			Content		
	K	Mg	Ca	K	Mg	Ca
		mg/g			mg/plant	
Cd0	65.10	4.39	8.33	98.44 a	6.66	12.55 a
Cd2,5	65.81	4.29	7.67	88.63 ab	5.78	10.33 b
Cd5	66.55	4.40	8.22	80.28 b	5.29	9.88 b
P	P= 0.6783	P= 0.9266	P= 0.3674	P= 0.0247*	P=0.1200	P= 0.0069**

**significant at 1%; *significant at 5%

It can be clearly observed that the concentration of cationic macro and microelements in the maize shoot decreased as affected by the application of increasing treatment rates (Table 1 and Table 2) and this decline was found not to be statistically important. Also, except for Mg, the concentration of macro and micronutrients analyzed declined too and this decrease was determined to be statistically important at 1% probability rate. The micro and macronutrient contents for the lowest (Cd0) and the highest application rates (Cd5) were 16.66 µg/plant and 12.13 µg/plant for Cu, 50.19 µg/plant and 37.54 for Zn, 167.02 µg/plant and 123 µg/ plant for Fe, 86.61 µg /plant and 68.39 µg/plant for Mn, 98.44 mg/plant and 80.28 mg/plant for K, 6.66 mg/plant and 5.29 mg/plant for Mg and 12.55 mg/plant and 9.88 mg/plant for Ca respectively. There are numerous studies that corroborates the results obtained in the present experiment. Cd application in increasing and excessive doses have been reported to decrease the uptake of macro and micronutrients hampering mineral nutrition of wheat and maize (Rizwan et al., 2016; Rehman et al., 2015; Rochayati et al., 2011). Moreover, Meda et al. (2007) reported that cadmium restricted the uptake of Fe (III) as a result of Fe and Cd application in maize. Chelate applications at increasing doses caused a decrease in Cu content in plant leaves, especially as a result of increasing lead and cadmium contents (Adiloglu, 2020). The presence of Cd in soils limits the uptake of many cationic nutrients. In this regard, Zhu et al. (2003) states that soils are contaminated with heavy metals such as Cd, Zn, Pb etc. In such cases, these metal ions interact with each other and affect the fate of each metal in soil-plant systems. Cd generally competes with Fe, Mn, Zn and Ca for plant uptake and this competition reduces the uptake and accumulation of micronutrients (Astolfi et al., 2012; Meda et al., 2007). Abbas et al. (2017) reported that while there was a positive correlation between the Cd concentration in the grain and the Cd concentrations in shoots and roots, there was a negative correlation with Zn, Mn concentrations and soil pH. Cd can cause changes in plant nutrient concentration and composition. Interactions with Cd and other metal nutrients such as Fe, Zn, Cu, and Mn have been reported in some uplands in various crops such as wheat (Zhang et al., 2002), tomatoes (Smith et al., 1983), barley (Wu and Zhang, 2002) and soybeans (Cataldo et al., 1983). Smith et al. (1983) reported a positive correlation between Cd and Zn, while Cataldo et al. (1983) reported a negative correlation between Cd and cationic micronutrients such as Fe, Zn, Cu, Mn. It is clearly observed in Table 2 and Table 3, that the Cd doses applied decreased the concentration and content of plant cationic nutrients in comparison to the control treatments. Compared to the control, the application dose of Cd2.5 decreased Cu, Zn, Fe, Mn, K, Mg, and Ca contents by 18%, 8%, 16%, 9%, 10%, 13%, and 18% respectively while the decrements, in comparison to the control at Cd5 treatment rate for Cu, Zn, Fe, Mn, K, Mg and Ca were 27%, 25%, 26%, 21%, 18%, 20%, and 21% respectively. These results are in line with a study conducted by Hernández et al. (1998) to investigate the effects of Cd application on Mn and Fe uptake of beans, they stated that Mn and Fe concentrations in both shoots and roots declined by 70 % and 77 % respectively, and that the decrements occurred since Cd disrupts the integrity and permeability of the plasma membrane by changing the functions of nutrient transporters and Mg^{+2}-ATPases. Furthermore, Veselov et al. (2003) reported a similar trend in wheat and underlined that, compared to the control plants, the wheat K uptake decreased by 56% as affected by the application of 0.04 mM Cd to the medium where wheat seedlings were grown.

CONCLUSIONS and RECOMMENDATIONS

Consequently, the findings obtained in the present study suggest that the application of increasing Cd doses decreased shoot dry weight as well as plant macro and microelement contents. While the highest macro and micronutrient values were obtained in the control treatment, the lowest values were obtained from Cd5 (5.0 mg kg^{-1}) treatment. On the contrary, the highest Cd concentration and contents were found in Cd5 (5.0 mg kg^{-1}) treatment. Furthermore, there is a correlation between Cd application rate and plant Cd content. Although Cd is not an essential nutrient for plants, it enters the food chain through plant uptake or can be washed out of the soil and contaminate water reservoirs thus creating a significant environmental problem. Ultimately, it is of great importance to prevent the contamination of soils with Cd for sustainable agriculture, human and environmental health through utilizing the data obtained in this study and the research available in the literature. If necessary, the Cd should be removed from the soil. For such practices, the two distinct commonly used methods should be employed: (1) phytoremediation and (2) bioremediation. The phytoremediation method can be employed using hyperaccumulator plants that can remove heavy metals from the contaminated soils by absorbing and accumulating them in their tissues, while the bioremediation technique utilizes microorganisms to conduct the same function.

REFERENCES

Abbas, T., Rizwan, M., Ali, S., Zia-ur-Rehman, M., Qayyum, M. F., Abbas, F., Hannan, F., Rinklebe, J. Ok, Y.S. 2017. Effect of biochar on cadmium bioavailability and uptake in wheat (*Triticum aestivum* L.) grown in a soil with aged contamination. Ecotoxicology environmental safety 140: 37-47.

Adiloglu, S. 2020. Interaction of some heavy metals with copper content in dock plant. Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi, 23(4): 1078-1084.

Asri, F.Ö., Sönmez, S., Çıtak, S. 2007. Kadmiyumun çevre ve insan sağliği üzerine etkileri. Derim, 24(1): 32-39.

Astolfi, S., Zuchi, S., Neumann, G., Cesco, S., di Toppi, L.S. Pinton, R. 2012. Response of barley plants to Fe deficiency and Cd contamination as affected by S starvation. Journal of experimental botany 63(3): 1241-1250.

Aznar-Sanchez, J.A., Piquer-Rodriguez, M., Velasco-Munoz, J.F. Manzano-Agugliaro, F. 2019. Worldwide research trends on sustainable land use in agriculture. Land Use Policy 87.

Bolat, İ., Kara, Ö. 2017. Bitki besin elementleri: Kaynakları, işlevleri, eksik ve fazlalıkları. Bartın Orman Fakultesi Dergisi, 19(1): 218-228.

Cataldo, D.A., Garland, T.R. Wildung, R. E. 1983. Cadmium uptake kinetics in intact soybean plants. Plant Physiology, 73(3): 844-848.

Clijsters, H., Van Assche, F. 1985. Inhibition of photosynthesis by heavy metals. Photosynthesis Research, 7(1): 31-40.

Çelim, S. 2018. Farklı demir formlarinin kadmiyum bulaştirilmiş yetiştrme ortaminda fasulye (*Phaseoulus vulgaris* L. Var. Nana) bitkisinin gelişimine, besin elementi ve kadmiyum alımına etkileri. Yüksek lisans. Fen Bilimleri Enstitüsü. Toprak BiİImi Ve Bitki Besleme Ana Bilim Dalı.Van yüzüncüyıl Üniversitesi (81).

Dağhan, H. 2011. Doğal kaynaklarda ağır metal kirliliğinin insan sağlığı üzerine etkileri. Mustafa Kemal Üniversitesi, 16(2): 15-25.

Dağhan, H., Uygur, V., Köleli, N., Arslan, M. 2013. Transgenik ve transgenik olmayan tütün bitkilerinde ağır metal uygulamalarının azot, fosfor ve potasyum alımına etkisi, Tarım Bilimleri Dergisi.

Erdoğrul, Ö., Tosyalı, C., Erbilir, F. 2005. Kahramanmaraş'ta yetişen bazı sebzelerde demir, bakır, mangan, kadmiyum ve nikel düzeyleri. KSÜ Fen ve Mühendislik Dergisi 8(2): 27.

Fan, J.L., Ziadi, N., Belanger, G., Parent, L. E., Cambouris, A., Hu, Z.Y. 2009. Cadmium accumulation in potato tubers produced in Quebec. Canadian Journal of Soil Science 89(4): 435-443.

Foy, C., Chaney, R.T., White, M. 1978. The physiology of metal toxicity in plants. Annual review of plant physiology 29(1): 511-566.

Hernández, L.E., Lozano-Rodrıguez, E., Gárate, A., Carpena-Ruiz, R. 1998. Influence of cadmium on the uptake, tissue accumulation and subcellular distribution of manganese in pea seedlings. Plant Science, 132(2): 139-151.

Jan, S.U., jamal, A., Sabar, M.A., Ortas, I., Isik, M., Aksahin, V., Alghamdi, H. A., Gul, S., Saqib, Z., Ali, M.I. 2020. Impact of zea mays l. waste derived biochar on cadmium immobilization and wheat plant growth. Pakistan Journal of Agricultural Sciences 57(5).

Kacar, B. 2009. Toprak analizleri. Nobel Yayınları No: 1387. Fen Bilimleri (90).

Kacar, B., İnal, A. 2008. Bitki Analizleri. Nobel Yayın No: 1241. Fen Bilimleri 63(1).

Kalınbacak, K., Yurdakul, İ., Gedikoğlu, İ. 2012. Buğdayda kadmiyumun toksiklik sınırının belirlenmesi ve bazı ekstraksiyon yöntemlerinin karşılaştırılması. Toprak Su Dergisi 1(1): 28-37.

Kopittke, P.M., Menzies, N.W., Wang, P., McKenna, B.A., Lombi, E. 2019. Soil and the intensification of agriculture for global food security. Environment International 132.

Lepp, N. 1981. The effect of heavy metal pollution on plants. 1(2): Appl. Sci. Publ., London.

Meda, A.R., Scheuermann, E.B., Prechsl, U.E., Erenoglu, B., Schaaf, G., Hayen, H., Weber, G., von Wirén, N. 2007. Iron acquisition by phytosiderophores contributes to cadmium tolerance. Plant Physiology 143(4): 1761-1773.

Okcu, M., Tozlu, E., Kumlay, A.M., Pehluvan, M. 2009. Ağır metallerin bitkiler üzerine etkileri. Alınteri Zirai Bilimler Dergisi 17(2): 14-26.

Ouzounidou, G. 1993. Changes in variable chlorophyll fluorescence as a result of Cu-treatment: dose-response relations in Silence and Thlaspi. Photosynthetica 29(3): 455-462.

Özbek, H., Kaya, Z., Gök, M., Kaptan, H. 1995. Toprak Bilimi (Çeviri). Ç, Ü, Ziraat Fakültesi 73.

Påhlsson, A.-M. B. 1989. Toxicity of heavy metals (Zn, Cu, Cd, Pb) to vascular plants. Water, Air, Soil Pollution 47(3-4): 287-319.

Rafique, M., Ortas, I., Rizwan, M., Sultan, T., Chaudhary, H. J., Işik, M. & Aydin, O. 2019. Effects of Rhizophagus clarus and biochar on growth, photosynthesis, nutrients, and cadmium (Cd) concentration of maize (*Zea mays*) grown in Cd-spiked soil. Environmental Science Pollution Research 26(20): 20689-20700.

Rehman, M. Z.-u., Rizwan, M., Ghafoor, A., Naeem, A., Ali, S., Sabir, M., Qayyum, M. F. 2015. Effect of inorganic amendments for in situ stabilization of cadmium in contaminated soils and its phyto-availability to wheat and rice under rotation. Environmental Science Pollution Research 22(21): 16897-16906.

Rizwan, M., Ali, S., Qayyum, M.F., Ibrahim, M., Zia-ur-Rehman, M., Abbas, T., Ok, Y.S. 2016. Mechanisms of biochar-mediated alleviation of toxicity of trace elements in plants: a critical review. Environmental Science Pollution Research 23(3): 2230-2248.

Rochayati, S., Du Laing, G., Rinklebe, J., Meissner, R., Verloo, M. 2011. Use of reactive phosphate rocks as fertilizer on acid upland soils in Indonesia: accumulation of cadmium and zinc in soils and shoots of maize plants. Journal of Plant Nutrition Soil Science 174(2): 186-194.

Sarwar, N., Ishaq, W., Farid, G., Shaheen, M. R., Imran, M., Geng, M. J. & Hussain, S. 2015. Zinc-cadmium interactions: Impact on wheat physiology and mineral acquisition. Ecotoxicology and Environmental Safety 122: 528-536.

Sarwar, N., Saifullah, Malhi, S. S., Zia, M. H., Naeem, A., Bibi, S., Farid, G. 2010. Role of mineral nutrition in minimizing cadmium accumulation by plants. Journal of the Science of Food and Agriculture 90(6): 925-937.

Shen, H., Christie, P., Li, X. 2006. Uptake of zinc, cadmium and phosphorus by arbuscular mycorrhizal maize (Zea mays L.) from a low available phosphorus calcareous soil spiked with zinc and cadmium. Environmental Geochemistry and Health 28(1-2): 111-119.

Sikka, R., Nayyar, V. 2012. Cadmium accumulation and its effects on uptake of micronutrients in indian mustard *Brassica juncea* (L.) Czern. grown in a loamy sand soil artificially contaminated with cadmium. Communications in Soil Science and Plant Analysis 43(4): 672-688.

Smith, G., G.C, S. EG, B. 1983. Cadmium-zinc interrelationships in tomato plants.

Sozubek, B., Belliturk, K., Saglam, M. T. 2014. Cadmium and zinc accumulation in maize influenced by zinc fertilizer in cadmium polluted soil. Türk Tarım ve Doğa Bilimleri Dergisi 1(Özel Sayı-2): 1407-1412.

Sönmez, İ., Kaplan, M., Sönmez, S. 2008. Kimyasal gübrelerin çevre kirliliği üzerine etkileri ve çözüm önerileri. Derim 25(2): 24-34.

Van Assche, F., Clijsters, H. 1990. Effects of metals on enzyme activity in plants. Plant, Cell Environment International 13(3): 195-206.

Veselov, D., Kudoyarova, G., Symonyan, M., Veselov, S. 2003. Effect of cadmium on ion uptake, transpiration and cytokinin content in wheat seedlings. Bulg Journal Plant Physiol 29(3-4): 353-359.

Wu, F., Zhang, G. 2002. Genotypic variation in kernel heavy metal concentrations in barley and as affected by soil factors. Journal of Plant Nutrition 25(6): 1163-1173.

Zhang, G., Fukami, M., Sekimoto, H. 2002. Influence of cadmium on mineral concentrations and yield components in wheat genotypes differing in Cd tolerance at seedling stage. Field Crops Research 77(2-3): 93-98.

Zhong, W. L., Li, J. T., Chen, Y. T., Shu, W. S. Liao, B. 2012. A study on the effects of lead, cadmium and phosphorus on the lead and cadmium uptake efficacy of Viola baoshanensis inoculated with arbuscular mycorrhizal fungi. Journal of Environmental Monitoring 14(9): 2497-2504.

Zhu, Y. G., Zhao, Z. Q., Li, H. Y., Smith, S. E., Smith, F. A. 2003. Effect of zinc-cadmium interactions on the uptake of zinc and cadmium by winter wheat (Triticum aestivum) grown in pot culture. Bulletin of Environmental Contamination and Toxicology 71(6): 1289-1296.