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Cadmium and Zinc Accumulation in Maize Influenced by Zinc Fertilizer in Cadmium Polluted Soil

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Abstract

Maize (Zea Mays L.) which is used in human diet as well as animal feeding and raw material for industry, is in the first rank among World cereal production for more than ten years. In parallel with the environmental pollution, heavy metal accumulation in soil is a serious problem. In this study, cadmium (Cd) is chosen as heavy metal in consequence of chemical similarity with zinc (Zn) which is an element that maize is very sensitive to its deficiency. The soils polluted with Cd in greenhouse conditions were fertilized with Zn. Maize grown in these soils was harvested six weeks after germination and analyzed for Cd and Zn. According to the results of analysis, fertilization with Zn increased Cd concentrations of maize significantly. Although Zn deficiency in maize is supplied by 20 ppm Zn in soil, the highest Cd concentrations in maize are determined at this dose of Zn fertilizer. Hence, maize growing in Cd polluted soils may cause toxic effects as maize needs Zn fertilization. Another noteworthy result of the study is the accumulation of Zn in shoots which is higher than roots while Cd accumulated mainly in roots. The case may be explained by chemical properties of these ions.

Keywords: Cadmium pollution, maize, soil, zinc fertilizer.

Mısırda Kadmiyum ve Çinko Birikiminin Kadmiyumla Kirlenmiş Topraklarda Çinko Gübresinden Etkilenmesi

Özet

İnsan beslenmesinin yanı sıra hayvan yemi ve endüstride hammadde olarak da kullanılan mısır (Zea Mays L.) Dünya tahıl üretiminde on yıldan fazla zamandır ilk sıradadır. Çevresel kirlenmeye paralel olarak toprakta ağır metal birikimi ciddi bir problemdir. Bu çalışmada, ağır metal olarak çinko (Zn) ile kimyasal benzerliğinden dolayı kadmiyum (Cd) kullanılmıştır. Çinko mısırın eksikliğine çok duyarlı olan bir elementtir. Topraklara laboratuar ortamında Cd eklenmiş ve gübre olarak çinko verilmiştir. Çimlenmeden altı hafta sonra mısır hasat edilmiş ve Cd ile Zn miktarları analiz edilmiştir. Analiz sonuçlarına göre, çinko ile gübreleme mısırdaki Cd konsantrasyonlarını önemli derecede arttırmıştır. Toprakta 20 ppm Zn ile mısırdaki çinko eksikliği giderilmiş olsa da bu dozda mısırda en yüksek Cd konsantrasyonu tespit edilmiştir. Cd ile kirlenmiş topraklarda mısır yetiştirilmesi, mısır çinko gübrelemesine ihtiyaç duyduğundan toksik etkilere neden olabilir. Bu çalışmadaki başka önemli bir sonuç kadmiyum daha çok köklerde birikirken çinko birikiminin saplarda köklerden daha fazla olmasıdır. Bu durum bu iyonların kimyasal özellikleri ile açıklanabilir.

Anahtar kelimeler: Çinko gübresi, kadmiyum kirlenmesi, mısır, toprak.

Introduction

Maize (Zea Mays L.) is used mainly in human diet, animal feeding and industry as raw material (Sahin, 2001). In Turkey, maize is in the third rank after wheat and barley among cereals both in harvested area and production more over ten years. Although total harvested area of cereals decreased in Turkey in ten years, harvested area of maize increased and also production of maize in tones increased more than two-fold in this time period. According to the statistical report released by FAO, maize is in the first rank among World cereal production for more than ten years. While the production of maize was less than 30% of total cereal production in 2002, it increased to 34% and upper in 2012 (FAO, 2014).

Maize has a good adaptability that can easily be grown in tropic, sub-tropic and temperate climates (Babaoglu, 2005). Maize can grow in various soil types best with 6-7 pH range that have good drainage, sufficient organic material and no salinity problem (Kilic, 2010). Degradation of soil in terms of changes in physical and chemical properties of soil affects the plants that grow in these soils. In parallel with the environmental pollution, heavy metal accumulation in soil is a serious problem. Cadmium (Cd) is among the important pollutants. Pollution of soils with cadmium may be in different ways. Phosphorus fertilizers are a source of cadmium (Grant and Sheppard, 2008). Also, industrial wastes and sewage are another source of cadmium pollution (Sparks, 2003). Besides, cadmium is found in the mining areas and generally cadmium exists in zinc ores (Das et al., 1997).

Cd has many negative effects on plants and animals. Cadmium toxicity generally changes water flow of the plant and disturbs the enzymes which lead to the growth problems in the plants (Pal et al., 2006; Cunha et al., 2008). Carcinogenic effects are seen in many animals that are exposed to high Cd concentrations. Besides kidney and lung illnesses, fragility of bones and cancer are among the problems that Cd causes in human beings who consume foods contain Cd or inhale Cd from air or cigarettes (Pal et al., 2006; Tezcan and Tezcan, 2007).

Cd and Zn have similar chemical properties. Both Cd and Zn are in the same group on periodic table which means they have both hexagonal crystal structure and have similar electron configurations (Petrucci et al., 2008). Zinc is an essential nutrient for the plants. Zinc is also among the micro elements that its deficiency is often seen in maize (Saglam, 2005). Eyupoglu et al. (1994) state in their report that 50 % of arable soils in Turkey was Zn deficient (Cakmak et al., 1998). Zn deficiency in maize generally causes depression of growth and light areas on the leaves (Kacar and Katkat, 2007).

The physical and chemical properties of soils such as Cd content, pH and competitive ions are responsible for the accumulation of Cd in plants. In a study, it is reported that Zn fertilizer did not have consistent effect on Cd content of seed of grain crops including maize and indicates that Cd content of the seeds were higher when grown in soils with high level of Cd (Rojas-Cifuentes et al., 2012). In another study, it is reported that Zn application to the soil increased Cd content of maize (Adiloglu et al., 2005). Similarly Narwal et al. (1993) states that increasing concentrations of Cd in soil increases the uptake of maize is more in presence of Zn application to soil. However, it is indicated in some studies that the application of Zn fertilizer to soil may decrease the concentrations of Cd in crops (Grant et al., 1998). Cd content of maize grown in acid soil is decreased with increasing Zn application but up to a point, it is increased when the cadmium content of the soil became to 10 ppm (Sozubek et al., 2013).

In this study, the aim is to determine the Cd and Zn content of maize grown in Cd polluted soil affected by Zn fertilizer. Cd was chosen as heavy metal in consequence of chemical similarity with Zn which is the element that maize is very sensitive to its deficiency.

Materials and Methods

The soil used in the experiment has a pH value of 6.52 which was taken from Tekirdag province of Turkey. The depth of soil taken was 0-20 cm (Jackson, 1965). The soil with 0.98 % organic material has a texture of sandy clay loam (SCL) and it is non-saline. Extractable Zn and Cd were determined as 0.290 ppm and 0.025 ppm respectively by using ICP-OES after Zn and Cd were extracted with DTPA method (Kacar, 2012; Lindsay and Norvell, 1978).

In each pot, 2 kilogram soils are put and Nitrogen, Phosphorus and Potassium fertilizers are added supply plant growth. Four kind of soil are prepared for the study, including three different doses of cadmium and one is without cadmium application. Four doses of zinc as fertilizer were applied with three repetitions. Four seeds of maize were planted to each pot and three plants were left after germination.

Six weeks after germination, shoots and roots of maize were harvested. Zn and Cd contents were determined by using ICP-OES after treated with nitric and perchloric acid (Kacar and Inal, 2008). For the statistical calculations, analysis of variance was performed and LSD multiple comparison test was used for comparing the means (Soysal, 2007).

Results and Discussion

The soils used in the study have an ideal pH and texture for maize growth. Although the soils are inadequate in terms of organic material, Mc Laughlin and Singh (1999) state that at pH 6-8, higher Cd concentrations were measured with higher organic matter content due to complexation of Cd by soluble organic substances. Therefore, limited content of organic material might be an advantage for minimizing the accumulation of Cd. The soil is poor in Zn content according to Gunes et al. (2010) and higher concentrations of Zn could be tried based on this deficiency.

Accumulation of Cd and Zn are determined separately in shoots and roots. Significant differences ($P<0.01$) are found between cadmium amounts of maize by the application of Zn fertilizer to the soils having different Cd concentrations (Table 1 and Table 2).

Table 1. Amount of Cd in shoots of maize grown in the soil with different Cd concntrations after Zn fertilization.

Cd concentration of soil (ppm)	Dose of Zn Fertilizer (ppm) 0	10	20	40
0	0.000±0.000 ^{B,a}	0.000±0.000 ^{C,a}	0.000±0.000 ^{D,a}	0.122±0.031 ^{D,a}
2,5	0.687±0.017 ^{AB,b}	1.802±0.260 ^{B,ab}	2.271±0.355 ^{C,a}	1.790±0.080 ^{C,ab}
5	0.811±0.159 ^{AB,c}	3.332±0.852 ^{A,b}	4.796±0.129 ^{B,a}	4.394±0.771 ^{B,ab}
10	1.483±0.030 ^{A,c}	4.257±0.149 ^{A,b}	6.737±0.674 ^{A,a}	6.228±0.175 ^{A,a}

1 Means in columns with different capital letters indicate significant differences between Cd amounts determined in the shoots of maize grown in the soils with different Cd doses at constant Zn fertilizer application at $p<0.01$. Means in rows with different small letters indicate significant differences between Cd amounts determined in the shoots of maize grown in the soils with constant Cd content by applying different doses of Zn fertilizer at $p<0.01$.

Table 2. Amount of Cd in roots of maize grown in the soil with different Cd concentrations after Zn fertilization

Cd concentration of soil (ppm)	Dose of Zn Fertilizer (ppm) 0	10	20	40
0	0.000±0.000 ^{B,a}	0.000±0.000 ^{C,a}	0.246±0.049 ^{C,a}	0.225±0.060 ^{C,a}
2,5	2.558±0.319 ^{B,a}	3.965±0.520 ^{C,a}	5.336±0.480 ^{B,a}	4.804±0.918 ^{B,a}
5	3.478±0.589 ^{AB,b}	9.488±2.090 ^{B,a}	9.399±0.318 ^{B,a}	9.349±0.649 ^{A,a}
10	7.073±1.450 ^{A,b}	15.868±3.250 ^{A,a}	18.357±0.929 ^{A,a}	10.190±1.250 ^{A,b}

1 Means in columns with different capital letters indicate significant differences between Cd amounts determined in the roots of maize grown in the soils with different Cd doses at constant Zn fertilizer application at $p<0.01$. Means in rows with different small letters indicate significant differences between Cd amounts determined in the roots of maize grown in the soils with constant Cd content by applying different doses of Zn fertilizer at $p<0.01$.

When the soil is unpolluted with Cd, detection of Cd started after 40 ppm Zn fertilizer application at the shoots and after 20 ppm Zn fertilizer application at the roots. However, when the soil is polluted with Cd, all measurements of Cd content is higher than the Cd amount allowed for cereals which is 0.1 ppm maximum stated in Turkish Food Codex Contaminant Regulations (Anonymous, 2014). The increase in Cd amount in maize with increasing soil Cd concentration can easily be seen on the left column of Figure 1. Previous studies already reveal the relationship between Cd concentrations of soil and plant is directly proportional.

10 and 20 ppm Zn application increased Cd contents of both roots and shoots at all soils. Cd should probably be displaced from soil exchange complexes to soil solution due to Zn addition. Therefore, Cd was up taken from soil solution to the maize. At 40 ppm Zn fertilization, Cd content of maize in both shoots and roots decreased when compared with 20 ppm and sometimes 10 ppm Zn fertilization. This decrease may be caused by Cd dilution in soil solution after addition of excess Zn fertilizer. Nevertheless, this decrease in Cd concentrations was not up to the concentrations determined in the plant grown in unpolluted soil.

As Zn fertilization is increased, Zn content of both shoots and roots of maize is increased in all repetitions (Table 3 and Table 4).

Table 3. Amount of Zn in shoots of maize grown in the soil with different Cd concntrations after Zn fertilization

Cd concentration of soil (ppm)	Dose of Zn Fertilizer (ppm) 0	10	20	40
0	13.440±1.040	15.907±2.630	21.877±3.070	29.170±1.230
2,5	15.790±0.799	17.830±1.170	25.320±0.751	25.477±0.650
5	12.443±1.510	23.500±4.890	24.257±0.101	26.340±2.460
10	16.187±0.816	18.773±1.580	27.070±1.170	30.080±4.180

($P>0.05$)

Table 4. Amount of Zn in roots of maize grown in the soil with different Cd concentrations after Zn fertilization

		Dose of Zn Fertilizer (ppm)			
		0	10	20	40
Cd concantration of soil (ppm)	0	14.923±1.570	15.653±1.180	23.667±5.320	29.337±2.480
	2,5	12.014±2.020	16.757±1.960	18.543±0.780	25.753±2.460
	5	12.137±0.786	14.490±1.490	17.863±0.619	29.993±3.200
	10	13.403±0.403	14.430±1.070	22.230±0.967	25.420±1.990

(P>0.05)

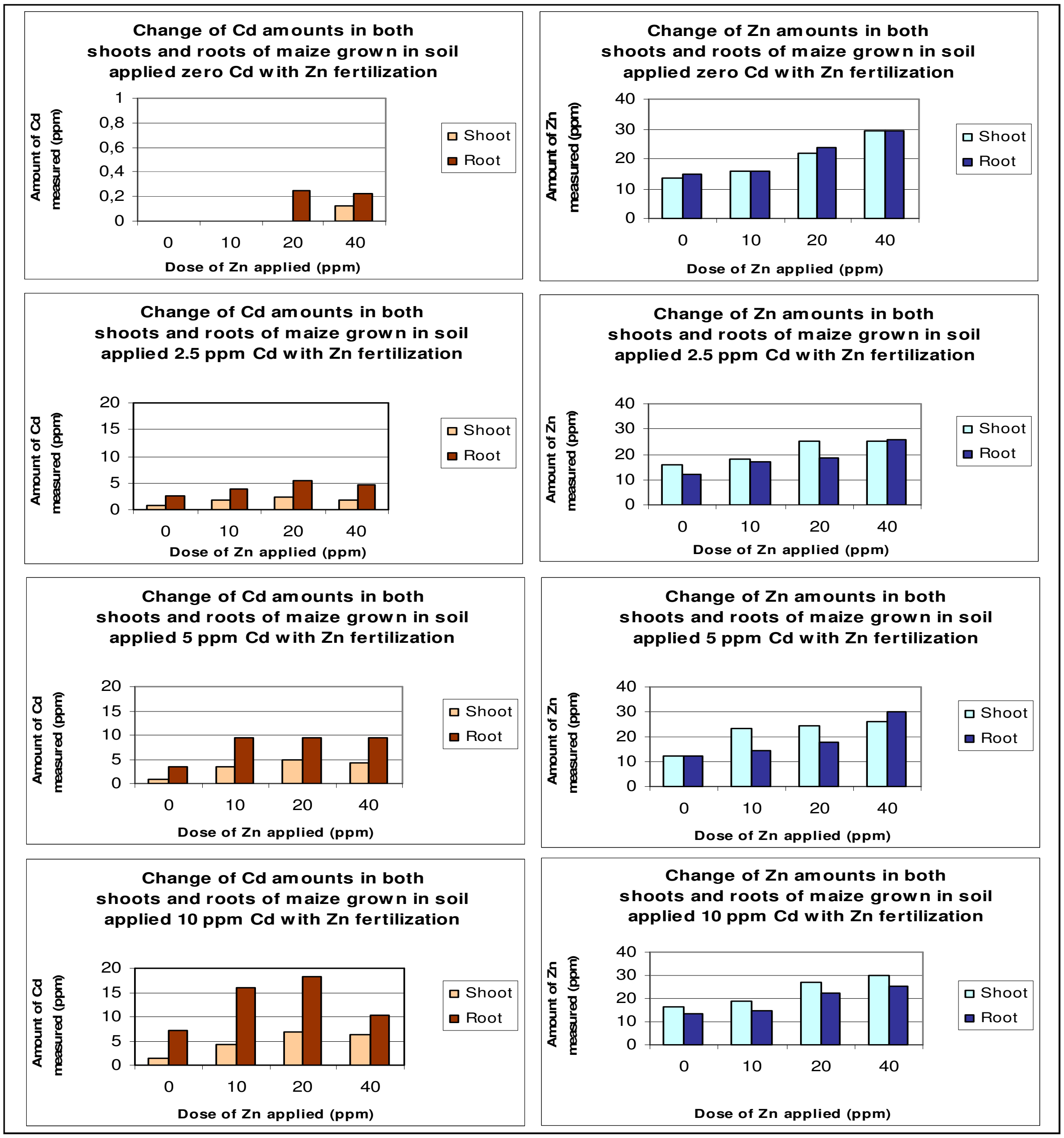

Figure 1. Changes of Cd and Zn amounts of maize with Zn fertilization.

There are not consistent and crucial effect of soil Cd concentrations on Zn content of maize. Increasing pollution of soils with Cd seems to be no significant effect on uptake of Zn by maize at same Zn fertilization rate.

The interesting result of the study is that, although Zn content of roots is higher than shoots when grown in unpolluted soil, it is mainly more in shoots than the roots of maize grown in polluted soil. In fact, in many resource the accumulation of toxic metals are in the order of roots> leaves> seeds

(Bini and Bech, 2014). Moreover, Cd is accumulated higher in roots than shoots in this study (Figure 1). Therefore the accumulation of Zn is expected to be higher in roots than shoots. However in this study accumulation of Zn is tended to be in shoots when the soil is polluted with Cd (Figure 1). This case may be related with plant transmission process under pollution stress and chemical properties of these ions such as higher mobility of Zn than Cd. While higher mobility of Zn causes Zn to transport to long distances in maize, Cd stayed in the roots abundantly. Briefly, Zn fertilization increased Zn accumulation of maize either the soil is polluted or unpolluted with Cd.

Conclusion

Pollution of soils with Cd is a contemporary serious problem since the existence of Cd in soil means the transfer of this toxic metal to the plants and thereby to the humans. Cd yields enzymatic problems in the plants that inhibit their growth and has toxic effects on animals and humans such as cancer. Maize is abundantly consumed crop in human diet as well as animal feeding. When soils are polluted with Cd, it is expected to transfer to maize from soil. Since Zn deficiency is commonly seen in maize and it has similar chemical properties with Cd, the question is appeared: Can Zinc fertilizer inhibit the accumulation of Cd in maize acting antagonist? The study showed that a general increase in Cd in maize after Zn fertilization in such kind of a soil with optimum pH value for maize growing. The detection and increase of Cd in maize after higher concentrations of Zn is observed although the soil was unpolluted. With increasing pollution of soil with Cd, the effect of Zn fertilizer on Cd accumulation in maize increased. Cd pollution in soils did not make a significant change on Zn uptake except for the fact that Zn accumulated more in shoots than roots. In short, Zn fertilization increased both Cd and Zn accumulation in maize either the soil is polluted with Cd or not. Therefore, one should be careful with Zn fertilization of maize in order not to increase the accumulation of Cd when supplying Zn necessity of maize.

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