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The Effect of Different Lime Forms on Cadmium Uptake of Durum Wheat Varieties

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ABSTRACT

Cadmium (Cd) accumulation in durum wheat (*Triticum durum* L.) and its human transport with food chain is a major environmental issue worldwide. The research was based on a pot experiment conducted on fifteen durum wheat cultivars, grown on acid soil pH 5.2. The effect of application of two different lime form (lime1=CaO; Calcium oxide and lime2=$CaCO_3$; limestone) and on shoot dry weight and shoot concentrations of cadmium (Cd). Durum wheat cultivars were grown in strongly acid soil pH 5.2 treated with control (lime0), lime1 (CaO_3 g kg^{-1} soil), lime2 (5.36 g $CaCO_3$) and Cd (5 and 10 mg kg^{-1} soil) and harvested after 62 days of growth under greenhouse conditions. Durum wheat cultivars without lime fertilization caused decrease in shoot growth, in all durum wheat cultivars and at high Cd treatment. On the other hand, application of lime to the soil resulted in an increase in dry matter yield at both Cd5 and Cd10 doses. While average shoot dry matter yield of lime0 conditions of cadmium 10 dose was 47 mg $plant^{-1}$, this yield increased to 120 mg $plant^{-1}$ in lime1 application and to 111 mg $plant^{-1}$ in lime2 application. Shoot Cd concentrations of durum wheat varieties caused a statistically significant decrease with lime1 and lime2 applications, whereas lime0 and lime2 applications of Cd5 dose caused 46% and 30% decrease in average Cd concentrations, respectively. The results indicated that all durum wheat cultivars were more susceptible to both without lime and Cd toxicity as compared to lime treatment. Cadmium toxicity in the shoot was relieved by lime1 and lime2 treatment. The results indicate that lime protects plants from Cd toxicity in durum wheat cultivars.

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Introduction

Cadmium (Cd), which is known as being a harmful pollutant and toxic to living organisms in ecosystem has an average concentration of 0.1 mg kg^{-1} in lithosphere and 0.53 mg kg^{-1} in agricultural soil. The Cd over 3 mg kg^{-1} in soil cause toxicity to plants. In the last two decades, the Cd concentration in soil has increased all over the world mainly due to anthropogenic sources i.e. industrial activities and phosphorus fertilizer applications, and lithology (Andresen and Hendrik, 2013). It is known that cadmium is readily uptaken by plants and easily transferred to the food chain (Korkmaz et al., 2010). The reason behind this critical effect is the relative mobility of Cd in soil-plant systems as well as its higher solubility in soil (Korkmaz et ak., 2017). Therefore, approximately 90% of the Cd exposure is caused by food consumption (Clemens et al., 2013). Cadmium accumulation in durum wheat grain is a growing concern. Cd mainly enters in wheat plants through roots (Oladzad-Abbasabadi et al., 2018). Durum wheat genotypes have the ability to accumulate Cd in grain to a more extent (McLaughlin et al., 1998; Erdem et al., 2012). Additionally, different durum wheat genotypes accumulate Cd in grain in a large variety (Clarke et al., 2002). Cd retention in roots and (Dunbar et al., 2003; Öztürk et al., 2003) and Cd remobilization from shoot tissues into grain also differ among genotypes. Wheats and durum wheat by-products constitute a major part of the daily diet of the human populations. Unfortunately, once taken into the human body, Cadmium is retained for many years, therefore, consumption of foods high in Cd may induce chronic toxicity (Korkmaz et al., 2018; Friberg, 2018). According to The World Health Organization (WHO), for an adult, maximum provisional tolerable intake limit should be 60 to 70 µg Cd per day. A limit of 0.1 mg kg^{-1} for cereal grains traded on international markets was also set by WHO (Borchers et al., 2010). Upon the strategies that may be applied to reduce plant-based accumulation of Cd, breading or genetic engineering to produce cultivars with low Cd accumulation, reducing

Cd availability in soil, and removal of Cd from soil by phytoremediation or soil washing are the most common ones (Bolan et al., 2013; Zhao and Huang, 2018). In order to increase soil pH, liming can be an effective and economical method for decreasing Cd availability in acidic paddy soils (Bolan et al., 2013; Zhu et al., 2016). A wide range of methods including physical, chemical and biological approaches are readily used for treatment of Cd-contaminated soils (Evanko and Dzombak, 1997; Mahabadi et al., 2007). However, with these traditional physical or physico-chemical remediation techniques, there are drawbacks such as being labor-intensive and costly for treating metal contaminated sites (Derome and Saarsalmi, 1999; Truong et al., 2010, Saltali and Korkmaz, 2015). On the other hand, treating the Cd-containing soils with lime as a chemical immobilizing amendment may be a cost-effective and feasible alternative way for the reduction of the availability of metals (Friesl et al., 2006; Trakal et al., 2011). It is known that alkaline chemical amendments increase metal sorption onto soil particles by increasing pH and also enhance heavy metal hydrolysis reactions and/or their co-precipitation, thereby act as immobilizing agents for some metals (Mench, 1998, Saltali, 2015). It is also a well-known fact that, in acidic soils Cd is relatively more soluble and more readily bioavailable for uptake by plants (Stacey et al., 2010). For these reasons, applying liming as a way to increase the pH of acidic soils is a convenient method to decrease Cd uptake by plants (Mench, 1998; Bolan et al., 2003; Kumarpandit et al., 2017).

The aim of the study was to determine the effect of liming on reduction of Cd in durum wheat varieties in cadmium soil contamination. The interaction of soil cadmium contamination with liming was assessed according to yield and the concentration of cadmium in durum wheat cultivars.

Materials and Methods

Material

The experiment soil used was collected from a farming field in the research area of Agriculture Faculty Application area, Ordu, Türkiye. The soil of experiment was measured by using described in Richards (1954). The main soil some characteristics used were acid soil (pH=5.04), the total concentration of Cd 0.32 mg kg^{-1}, the DTPA-extractable Cd 0.011 mg kg^{-1}, soil Zn-deficient soil containing 0.15 mg DTPA-extractable Zn, organic matter 1.6% , $CaCO_3$ 0.9% and soil had a clay texture. The total concentration of Cd and the DTPA-extractable Cd were determined by using the methods given in Schlichting and Blume (1966) and Lindsay and Norvell (1978), respectively. The cultivars of durum wheat (*Triticum turgidum L.*) used in the experiment; Fırat93, Çeşit1252, Kızıltan91, Şahinbey, Meram2002, Selçuklu97, ANK98, Eminbey, Yelken, Sarıbaşak, Fuatbey, Sham-I, Altın, Güneyyıldızı and İmren.

Method

Plants were grown under greenhouse conditions in number 7 plastic pots containing 1.65 kg soil. In experiment, lime and Cd were applied to the soil simultaneously prior to the initiation of sowing and were treated with 2 levels of Cd (5 and 10 mg kg^{-1} soil) in the forms of $3CdSO_4*8H_2O$ and the liming materials of the soil 3 levels were added into the pots before sowing in equal Ca amount corresponding with lime0=control, lime1=3 g CaO and lime2= 5.36 g $CaCO_3$ per kg of the soil. The pots were applied 200 mg N kg^{-1} soil as $Ca(NO_3)_2$, 100 mg P kg^{-1} soil as KH_2PO_4, 125 mg K kg^{-1} soil as KH_2PO_4, and 1.0 mg Zn kg^{-1} soil s $ZnSO_4.7H_2O$ as a basal treatment. In experiment, all nutrients were mixed thoroughly with soil before potting. The experiment was conducted completely randomized design. Treatment was carried out in pots in four replications. During the growth period the pots were wetted with deionized water daily for 63 day. All pots were randomized every 3-5 days under greenhouse conditions. After 63 days of growth, shoots were harvested and dried at 70 ^{o}C for determination of shoot dry weight and concentrations of Cd. The digestion of harvested plants was performed in a microwave oven using 2 ml of 35% H_2O_2 and 5 ml of 65% HNO_3. The Cd and Zn concentrations in the extracts of digestions were analyzed using an ICP-OES (Varian Vista) (Bataglia et al., 1983). Total N in shoot biomass was determined by Kjeldhal's method. The measurements were verified using the certified Cd and Zn values of leaf obtained from the National Institute of Standards and Technology Peach leaves (Standard Reference Material, 1547). Soil pH was twice measured at harvest after 9 weeks of plant growth and before sowing.

Statistical Analysis

One-way analysis of variance (ANOVA) was performed for shoot biomass of Cd concentration using SPSS 21.0.

Results and Discussion

The application of two different forms of lime to the acidic soil caused statistically significant increases in soil pH values (Table 1). At the beginning of the trial, for the 15 different durum wheat varieties used in the study, the average pH value of the soils of cadmium 5 dose (Cd5) was 4.93. This value increased to 5.95 in lime1 application and 6.13 in lime2 application. On the other hand, in this case of cadmium 10 (Cd10) application, the average pH level of control applications was 4.95, while it increased to pH 6.04 in lime1 application and 6.56 in lime2 application (Table 1). As can be seen from the results, the pH of the soil increased in both lime form applications. However, although the highest pH increase was observed in lime2 application, this difference was statistically insignificant (Table 1). Chen et al. (2018) investigated the effect of increasing doses of $CaCO_3$ (0, 2.25, 4.5 and 7.5 t ha^{-1}) on the Cd concentration of paddy grain under field conditions for 2 years. The researchers reported that the highest $CaCO_3$ (7.5 t ha^{-1}) dose increased the soil pH from the initial value of 5.5 to 6.5 and consequently the Cd concentration extractable with $CaCl_2$ decreased in both years with increasing soil pH.

For centuries, lime or limestone application in order to increase the soil pH has been accepted as a common and effective practice in agricultural activities (Goulding and Blake, 1998). Due to the reduction of neutralizing capacity of some of the lime, especially after a heavy rainfall, some variations may be observed in the pH trends, as occurred during the trial. It should also be noted that, soil type and fertilizer applications made to the trees by farmers are also have significant impact (Goulding and Blake, 1998).

Durum wheats were more susceptible to strongly acid soil condition. In lime0 (control) with increasing Cd doses, shoot growth severely decreased. In lime0 and Cd5 mg kg^{-1} treatment, shoot dry weight found significant differences between the varieties and the mean of all cultivars (Table 2). Under cadmium 5 and lime0 application conditions, the dry matter yield of durum wheat genotypes varied between 42-79 mg $plant^{-1}$ and the average yield was 57 mg $plant^{-1}$. In the application of Cd10 and lime0, the dry matter yield of durum wheat genotypes varied between 38-63 mg plants and the average yield was 47 mg $plant^{-1}$. Among durum wheat varieties, the lowest dry matter yield was obtained in Imren (42 mg $plant^{-1}$) and the highest dry matter yield was obtained in Fırat-93 (79 mg $plant^{-1}$) in Cd5 lime0 application. In Cd10 lime0 application, the lowest dry matter yield was obtained in Sarıbaşak and Selçuklu varieties (38 mg $plant^{-1}$) and the highest dry matter yield was obtained in Fuatbey variety (63 mg $plant^{-1}$). According to the results obtained, it has been revealed that durum wheat varieties give different responses to Cd applications. Koleli et al. (1998) investigated the sensitivity of different cereal species to Cd toxicity in a study and found that there are significant differences in terms of resistance to Cd toxicity between both cereal types and varieties of the same species.

Physical/chemical characteristics of soil were significantly affected by the liming as well as the Cd availability. Compared to the control application (lime0), both lime1 and lime2 treatments resulted in statistically significant increases in dry matter yields at Cd5 and Cd10 doses of durum wheat varieties (Table 2). For example, while the average dry matter yield of durum wheat varieties at Cd10 dose of lime0 application was 47 mg $plant^{-1}$, it increased to 120 and 111 mg $plant^{-1}$ in lime1 and lime2 applications, respectively (Table 2). This increase in dry matter yield is caused by the decrease in Cd availability in the soil as a result of the increase in soil pH with liming (Table 1). Evaluation of the results in terms of different lime forms revealed that the highest increase in dry matter yield occurred in lime1 applications. While the average dry matter yield of lime0 applications at the doses of Cd5 and Cd10 was 57 mg $plant^{-1}$ and 47 mg $plant^{-1}$, respectively, these values were on average 142 mg $plant^{-1}$ in Cd5 and 120 mg $plant^{-1}$ in Cd10 in the case of lime1 applications. (Table 2).

Among the factors affecting the solubility and bio-availability of Cd in soil media, soil pH is one of the most vital ones (Evans et al., 1995). This is mainly due to the fact that, applying lime to Cd polluted soils increases soil pH and reduces the mobility of metals (Castaldi et al., 2005).

There was large variation in shoot Cd concentration between 15 cultivars under increasing Cd treatment. As expected, in without lime0 (control) and increasing Cd application significantly increased Cd concentration of durum wheat cultivars. At both lime1 and lime2 form of treatment, according to all durum wheat cultivars had a less Cd concentration. Lime0 with increasing Cd applications, with Cd5 application, Cd concentration found range 3.83-9.59 mg kg^{-1} in shoot of all cultivars and Cd10 treatment 12.0-25.9 mg kg^{-1} in shoot. Under the conditions of Cd5 and Cd10 doses without lime applications, the varieties with excess Cd in the shoot biomass were revealed to be Fuatbey (9.59 mg kg^{-1}) and Imren (25.9 mg kg^{-1}) varieties, respectively (Table 3). In a previous study done by Koleli et al. (2004) it was reported that increasing doses of Cd in soil enhances Cd concentration of shoots the highest Cd level being obtained as a Cd dose of 25 mg kg^{-1}. The accumulation of higher Cd levels in grain, which is not common for bread wheats (*T. aestivum* L.), is stipulated by the genetic propensity of durum wheats (*Triticum turgidum* L. var durum) (Wolnik et al., 1983). As durum wheat genotypes have the ability to accumulate higher Cd in grain with respect to bread wheat genotypes, Cd accumulation especially in durum wheat is a growing concern (McLaughlin et al., 1998).

Table 1. The Effect of Lime Applications on Soil Ph of Durum Wheat Varieties Grown Under Cd5 and Cd10 Doses

Genotype	Cd5			Cd10		
	Lime0	Lime1	Lime2	Lime0	Lime1	Lime2
Fırat-93	4.97^{aB}	5.73^{bA}	5.76^{bA}	4.74^{bcB}	6.25^{abA}	5.91^{cA}
Çeşit-1252	4.82^{bAB}	5.77^{bB}	6.10^{abA}	4.65^{cC}	5.59^{cB}	6.51^{bA}
Kızıltan-91	5.13^{aC}	6.09^{abA}	5.75^{bB}	5.43^{aB}	6.77^{aA}	5.93^{cB}
Şahinbey	4.70^{bB}	5.66^{bAB}	6.22^{abA}	4.95^{bB}	6.33^{abA}	6.70^{abA}
Meram-2002	5.02^{aB}	6.23^{aA}	6.50^{aA}	5.02^{bC}	5.82^{bcB}	7.16^{aA}
Selçuklu97	4.95^{aC}	5.88^{bB}	6.54^{aA}	4.99^{bB}	5.90^{bcA}	6.17^{bA}
ANK98	4.81^{bC}	5.45^{cB}	6.67^{aA}	4.96^{bC}	5.42^{abB}	6.47^{bA}
Eminbey	4.99^{aB}	6.15^{aA}	6.24^{abA}	5.04^{bB}	6.45^{abA}	6.48^{bA}
Yelken	4.92^{abB}	6.14^{aA}	6.19^{abA}	4.93^{bB}	6.14^{bA}	6.30^{bcA}
Sarıbaşak	4.94^{abB}	6.06^{abA}	6.45^{aA}	4.86^{bB}	6.13^{bA}	6.63^{bA}
Fuatbey	5.00^{aB}	5.79^{bA}	5.99^{bA}	4.91^{bB}	6.51^{abA}	6.90^{aA}
Sham-I	5.04^{aB}	5.65^{bA}	5.57^{cA}	4.90^{bC}	5.79^{bcB}	7.16^{aA}
Altın	4.77^{bB}	6.03^{abA}	5.94^{bA}	4.71^{bcC}	5.71^{bcB}	6.97^{aA}
Güneyyıldızı	4.88^{bC}	6.35^{aA}	5.84^{bB}	4.87^{bB}	6.00^{bA}	6.34^{bcA}
İmren	5.06^{aB}	6.30^{aA}	6.57^{aA}	4.98^{bC}	5.81^{bcB}	6.83^{abA}
Average	4.93^{B}	5.95^{A}	6.13^{A}	4.95^{C}	6.04^{B}	6.56^{A}

The means indicated that is not significantly different (P<0.05); The means indicated taht is not significantly different (P<0.05)

Table 2. The Effect of Lime Applications on Dry Matter Yield of Durum Wheat Varieties Grown Under Cd5 and Cd10 Doses

Genotype	Cd5			Cd10		
	Lime0	Lime1	Lime2	Lime0	Lime1	Lime2
Fırat-93	79^{aC}	160^{aA}	116^{bB}	60^{aC}	133^{aA}	115^{bcB}
Çeşit-1252	58^{bC}	146^{bA}	113^{bB}	53^{abC}	113^{bcA}	102^{cB}
Kızıltan-91	61^{bC}	139^{cA}	113^{bB}	43^{bB}	105^{cA}	94^{cA}
Şahinbey	69^{abB}	155^{abA}	144^{aA}	59^{aC}	119^{bB}	140^{aA}
Meram-2002	53^{bcC}	142^{bcA}	129^{abB}	49^{bC}	130^{aA}	118^{bB}
Selçuklu97	54^{dC}	130^{cA}	95^{cB}	38^{cC}	110^{bcA}	90^{cB}
ANK98	46^{bC}	147^{bA}	132^{abB}	40^{cB}	122^{abA}	118^{bA}
Eminbey	59^{bcB}	124^{dA}	111^{bA}	53^{abC}	119^{bA}	102^{cB}
Yelken	54^{cC}	123^{dA}	105^{bB}	42^{bC}	118^{bA}	98^{cB}
Sarıbaşak	51^{abB}	144^{bA}	137^{aA}	38^{cB}	133^{aA}	125^{bA}
Fuatbey	67^{abB}	149^{bA}	135^{aA}	63^{aB}	130^{aA}	121^{bA}
Sham-I	47^{dC}	150^{bA}	130^{aB}	39^{cB}	124^{abA}	121^{bA}
Altın	51^{cC}	149^{bA}	128^{aB}	44^{bC}	118^{bA}	100^{cB}
Güneyyıldızı	57^{bC}	154^{abA}	139^{aB}	49^{bB}	130^{aA}	124^{bA}
İmren	42^{dC}	125^{dA}	98b^{cB}	39^{cB}	95^{cA}	91^{cA}
Average	57^{C}	142^{A}	122^{B}	47^{B}	120^{A}	111^{A}

The means indicated that is not significantly different ($P<0.05$); The means indicated that is not significantly different ($P<0.05$)

Table 3. The effect of lime applications on shoot Cd concentration of durum wheat varieties grown under Cd5 and Cd10 doses

Genotype	Cd5			Cd10		
	Lime0	Lime1	Lime2	Lime0	Lime1	Lime2
Fırat-93	4.22^{eA}	2.26^{cC}	3.63^{dB}	13.7^{cA}	6.60^{cC}	8.41^{bB}
Çeşit-1252	4.13^{eA}	2.93^{bcB}	3.85^{dA}	13.8^{cA}	6.10^{cdC}	8.56^{bB}
Kızıltan-91	3.91^{efA}	2.87^{bcB}	3.64^{dA}	16.0^{bA}	6.50^{cC}	8.13^{bcB}
Şahinbey	3.97^{efA}	2.77^{bcB}	3.50^{dA}	17.3^{bA}	5.88^{dC}	8.89^{bB}
Meram-2002	4.22^{eA}	2.47^{cB}	2.74^{eB}	15.9^{bcA}	5.86^{dC}	7.19^{cB}
Selçuklu97	4.45^{eA}	3.43^{bB}	4.45^{cA}	16.1^{bA}	6.09^{cdC}	9.21^{abB}
ANK98	4.33^{eA}	2.54^{cC}	3.29^{dB}	19.5^{abA}	6.77^{bcC}	9.62^{abB}
Eminbey	3.83^{fA}	2.43^{cB}	2.36^{eB}	16.4^{bA}	6.70^{bcC}	8.62^{bB}
Yelken	8.17^{bA}	4.02^{abB}	5.01^{bB}	21.4^{aA}	7.23^{bC}	10.3^{aB}
Sarıbaşak	5.99^{dA}	2.33^{cC}	3.37^{dB}	12.0^{cA}	6.33^{cC}	10.6^{aA}
Fuatbey	9.59^{aA}	4.52^{aC}	6.72^{aB}	18.7^{ab}A	6.29^{cC}	9.60^{abB}
Sham-I	7.35^{cA}	3.38^{bB}	4.15^{cB}	18.8^{abA}	7.76^{bC}	9.50^{abB}
Altın	8.75^{abA}	4.28^{aB}	4.88^{bB}	24.3^{aA}	7.33^{bC}	11.1^{aB}
Güneyyıldızı	6.41^{dA}	3.41^{bB}	4.14^{cB}	21.2^{aA}	9.75^{aB}	9.68^{abB}
İmren	9.46^{aA}	4.21^{aC}	6.44^{aB}	25.9^{aA}	9.90^{aB}	9.78^{abB}
Average	5.92^{A}	3.19^{B}	4.14^{B}	18.1^{A}	7.01^{C}	9.28^{B}

The means indicated that is not significantly different ($P<0.05$); The means indicated that is not significantly different ($P<0.05$)

The increase in Cd concentration in shoots at Cd5 and Cd10 doses without lime application caused a statistically significant decrease with lime1 and lime2 applications to the soil. The average Cd concentration of lime0 application of Cd5 dose, which was 5.92 mg kg^{-1}, decreased by 46% to 3.19 mg kg^{-1} with lime1 application to the soil, while decreasing 30% to 4.14 mg kg^{-1} with lime2 application. Moreover, Cd concentration, which was 18.1 in lime0 application at Cd10 dose, decreased by 61.3% to 7.01 mg kg^{-1} with lime1 application, and decreased by 48.7% to 9.28 mg kg^{-1} with lime2 application. As clearly seen from the results, it was observed that lime1 treatment caused a greater decrease in shoot Cd concentrations at both Cd5 and Cd10 doses (Table 3).

Many authors explained that plant nutrient uptake is highly correlated with pH (Dakora and Phillips, 2002; Hinsinger et al., 2003). Soil pH has a crucial role in Cd solubility and mobility in soil. So, Cd is accumulated in the plant leaves (Yu et al., 2016). Liming of acidic soils raise the soil pH and enhances the immobilization of Cd^2. As a result, the reduced mobility and increase availability of Cd and its uptake by durum wheat plants (Bian et al., 2016). Similar to the results we obtained, Chen et al. (2018) found that increasing doses of $CaCO_3$ (0, 2.25, 4.5 and 7.5 t ha^{-1}) in field conditions for a period of 2 years caused a decrease in Cd concentrations in paddy grain and the maximum decrease was revealed as 70-80% reduction at 7.5 t ha^{-1} $CaCO_3$ application. Shi et al. (2019) reported that 1.5 t ha^{-1} $CaCO_3$ application to paddy plant under field conditions caused a decrease of 34.9% under intermittent irrigation conditions and 55.8% under flood conditions in grain Cd concentrations.

It has been observed that cadmium applications cause a decrease in shoot N concentrations in 15 different durum wheat varieties. While the average N concentration was 2.41% under the lime0 Cd5 dose conditions, it was observed that it decreased to 1.63% in the case of lime0 Cd10 dose (Table 4). Chaffei et al. (2004) reported that with the application of Cd to the tomato plant, the shoot N concentration decreased statistically significantly.

According to Hernandez et al. (1996) the decrease in the N concentrations of plants with Cd applications was due to the prevention of nitrate reductase activity in the root zone of Cd and hence the decrease in nitrate absorption. This decrease in N concentrations with cadmium application caused a statistically significant increase in N concentrations with lime1 and lime2 applications (Table 4). For example, while the average N concentration of durum wheat varieties under Cd10 lime0 application was 1.63%, it was observed that at the same Cd dose it increased to 2.14% in lime1 application and 2.46% in lime2 application (Table 4). The results caused a decrease in the availability of Cd with lime applications and an increase in the N concentrations of the plants accordingly. As a result of the increase in soil pH and Ca, liming has a positive impact on mineral N content (Brady and Weil, 2002; Tisdale et al., 2005).

One of the important effects of Cd toxicity in plants is its interaction with mineral nutrients (especially microelements). While the average Zn concentration of durum wheat varieties was 38.2 mg kg^{-1} under the lime0 Cd5 dose conditions, it was observed that it decreased to an average of 34.1 mg kg^{-1} at the lime0 Cd10 dose (Table 5). Vasiliadou and Dordas, (2009) reported that there were statistically significant decreases (-0.542^{***}) in shoot Zn concentrations with increasing doses of Cd application to tobacco varieties. With increasing Cd application decreased in Zn concentrations. It may have been the result of the antagonistic relationship seen between Cd * Zn. The fact that the plants grown with zinc deficiency take more Cd is related to the competition of Zn and Cd, as they are similar according to their chemical features, for absorption points on membranes (Cakmak et al., 2000) and can also be attributed to the increase in membrane permeability in the case of Zn deficiency (Cakmak and Marschner, 1988).

Table 4. The effect of lime applications on shoot N concentration of durum wheat varieties grown under Cd5 and Cd10 doses

Genotype	Cd5			Cd10		
	Lime0	Lime1	Lime2	Lime0	Lime1	Lime2
Fırat-93	2.55^{aB}	2.84^{abA}	2.51^{bB}	1.76^{aB}	2.04^{abA}	2.22^{bA}
Çeşit-1252	2.59^{aB}	2.74^{bA}	2.57^{bB}	1.83^{aB}	1.87^{bB}	2.15^{bA}
Kızıltan-91	2.74^{aAB}	2.92^{aA}	2.57^{bB}	1.56^{bB}	1.93^{bA}	2.20^{bA}
Şahinbey	2.39^{abB}	2.85^{abA}	2.68^{abA}	1.58^{bC}	2.09^{abB}	2.43^{bA}
Meram-2002	2.15^{bC}	2.93^{aA}	2.52^{bB}	1.72^{aB}	2.10^{abA}	2.46^{bA}
Selçuklu97	2.17^{bB}	2.83^{abA}	2.55^{bAB}	1.74^{aC}	2.05^{abB}	2.57^{abA}
ANK98	2.33^{abB}	2.64^{bA}	2.73^{aA}	1.62^{bB}	2.12^{abA}	2.42^{bA}
Eminbey	2.56^{aB}	2.75^{bA}	2.80^{aA}	1.47^{bB}	2.18^{aA}	2.54^{abA}
Yelken	2.76^{aA}	2.65^{bA}	2.77^{aA}	1.50^{bB}	2.27^{aA}	2.52^{abA}
Sarıbaşak	2.91^{aA}	2.77^{bA}	2.66^{abA}	1.55^{bB}	2.34^{aA}	2.48^{bA}
Fuatbey	2.33^{aB}	2.77^{bA}	2.58^{bA}	1.59^{bB}	2.17^{aA}	2.43^{bA}
Sham-I	2.08^{aB}	2.77^{bA}	2.46^{bA}	1.58^{bB}	2.22^{aA}	2.23^{bA}
Altın	2.03^{aB}	2.77^{bA}	2.68^{aA}	1.50^{bC}	2.21^{aB}	2.83^{aA}
Güneyyıldızı	2.27^{abB}	2.65^{bA}	2.72^{aA}	1.69^{abC}	2.20^{aB}	2.70^{aA}
İmren	2.36^{abB}	2.77^{bA}	2.79^{aA}	1.78^{aC}	2.34^{aAB}	2.71^{aA}
Average	2.41^{B}	2.78^{A}	2.64^{A}	1.63^{C}	2.14^{B}	2.46^{A}

The means indicated that is not significantly different (P<0.05); The means indicated that is not significantly different (P<0.05)

Table 5. The Effect of Lime Applications on Shoot Zn Concentration of Durum Wheat Varieties Grown Under Cd5 and Cd10 Doses

Genotype	Cd 5			Cd 10		
	Lime0	Lime1	Lime2	Lime0	Lime1	Lime2
Fırat-93	38.2^{bcA}	24.3^{cB}	37.7^{bA}	24.2^{cA}	21.4^{cA}	20.0^{dA}
Çeşit-1252	50.8^{aA}	31.9^{bB}	33.8^{cB}	33.9^{abA}	26.7^{bcB}	34.4^{abA}
Kızıltan-91	42.6^{bA}	37.4^{aB}	46.3^{aA}	44.2^{aA}	30.1^{bB}	34.9^{abB}
Şahinbey	31.7^{cA}	27.4^{bcA}	31.7^{cA}	27.5^{bA}	24.8^{cA}	25.1^{cA}
Meram-2002	40.2^{bA}	33.4^{bB}	35.6^{bcB}	33.2^{abA}	27.8^{bA}	32.4^{bA}
Selçuklu97	35.8^{bcC}	40.0^{aB}	51.1^{aA}	35.7^{abA}	34.4^{abA}	37.1^{aA}
ANK98	41.6^{bA}	40.1^{aA}	44.0^{abA}	38.0^{aA}	36.2^{aA}	36.0^{aA}
Eminbey	30.3^{cA}	32.8^{bAB}	35.5^{bcA}	28.9^{bB}	35.2^{abA}	35.4^{aA}
Yelken	30.9^{cB}	38.2^{aA}	40.6^{bA}	29.6^{bB}	35.3^{abA}	31.8^{bB}
Sarıbaşak	32.0^{cA}	21.3^{cB}	25.3^{dB}	33.7^{abA}	22.7^{cB}	20.6^{dB}
Fuatbey	47.0^{aA}	31.5^{bB}	37.0^{bAB}	41.7^{aA}	28.7^{bB}	24.8^{cB}
Sham-I	42.3^{bA}	26.9^{bcB}	28.1^{cB}	38.4^{aA}	21.8^{cB}	26.9^{cB}
Altın	33.5^{cB}	37.5^{aB}	46.6^{aA}	31.1^{bB}	38.7^{aA}	39.2^{aA}
Güneyyıldızı	32.0^{cA}	36.5^{abA}	31.8^{cA}	30.5^{bA}	28.6^{bAB}	26.1^{cB}
İmren	44.8^{abA}	39.8^{aA}	43.2^{abA}	40.6^{aA}	37.7^{aA}	36.8^{aA}
Average	38.2^{A}	33.3^{B}	37.9^{A}	34.1^{A}	30.0^{B}	30.8^{B}

The means indicated with the same capital letter in the same row are not significantly different (P<0.05); The means indicated with the same small letter in the same column are not significantly different (P<0.05).

It was observed that there were statistically significant decreases in Zn concentrations of durum wheat varieties under lime1 and lime2 applications of Cd5 and Cd10 doses (Table 5). For example, while the average Zn concentration in the lime0 application of the Cd10 dose was 34.1 mg kg^{-1}, these values decreased to 30.0 mg kg^{-1} and 30.8 mg kg^{-1} with the lime1 and lime2 applications, respectively (Table 5).

The concentration of the micronutrients in the soil solution is dependent on soil pH, redox potential and soil organic matter content (Sinclair et al., 1990). An increase in pH can decrease the concentration of micronutrients (Marschner and Rengel, 2012). Chen et al. (2018) reported that increasing doses of $CaCO_3$ (0, 2.25, 4.5 and 7.5 t ha^{-1}) in field conditions during 2 years caused a 5-15% decrease in the Zn concentrations of paddy grain.

Conclusions

The durum wheat biomasses increased in shoots indicated significant liming-Cd interactions in this experiment. With that regard, differences were found in wheat shoot as affected by acid soil and liming soil conditions Cd concentrations were considerably lower compared to acid soil. The durum wheat exhibited greater sensitivity to the accumulation of Cd, especially under acid soil and Cd toxic conditions thus, durum wheat yield was increased with lime1 and lime2 treatments. Thus, it is not advised to cultivate durum wheat with acid soils. The decline in Cd concentration of durum wheat with the application of liming suggested that the toxic effects of Cd may be prevented or alleviated by liming application. If durum wheat needs to be cultivated on Cd-polluted soils, cultivars with high ability to reduce accumulation of Cd in grain should be preferred to reduce the Cd accumulation in grain. Soil amelioration by liming had considerably effects on decreases of Cd concentrations in fifteen durum wheat cultivars.

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