Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi
Journal of AgriculturalFaculty of GaziosmanpasaUniversity
http://ziraatdergi.gop.edu.tr/

Araştırma Makalesi/*ResearchArticle*

JAFAG
ISSN: 1300-2910
E-ISSN: 2147-8848
(2017) 34 (1), 179-188
doi:**10.13002/jafag4197**

Role of Potassium in Alleviation of Cadmium Toxicity in Sunflower (*Helianthus annuus* L.)

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Alındığı tarih (Received): 24.12.2016 Kabul tarihi (Accepted): 06.03.2017
Online Baskı tarihi (Printed Online): 18.04.2017 Yazılı baskı tarihi (Printed): 02.05.2017

Abstract: Using excessive commercial fertilizers in agricultural lands is resulted in accumulation of toxic heavy metals in soils and this causes toxicity in plant organs and losses of crop yield and quality in plants. In this study, response of sunflower (*Helianthus annuus* L.) plant to the mutual effects of cadmium (Cd) and potassium (K) were investigated. For this reason, five levels of Cd (0, 0.1, 0.3, 0.6, and 1.2 mM) and three levels of K (0, 200, and 400 mg kg^{-1}) were applied to the soil. According to the results, increasing Cd levels decreased the shoot dry weight (DW), root DW, root length, total chlorophyll (Chl) and carotenoid (Car) contents, the shoot bio-concentration factor (BCF), and translocation factor (TF), whereas they increased the membrane permeability (MP) of the leaves and total accumulation rate (TAR) of Cd in sunflower. In the absence or presence of K, the shoot and root Cd concentration and shoot Cd uptake increased remarkably with Cd applications. Also, applied K levels increased significantly the K concentration and K uptake by both shoot and root.

Keywords: Bio-accumulation, chlorophyll, dry weight, *Helianthus annuus* L., translocation

Ayçiçeği (*Helianthus annuus* L.) Bitkisinde Kadmiyum Toksisitesinin Önlenmesinde Potasyumun Rolü

Öz: Tarım topraklarında ticari gübrelerin fazlaca kullanılması bitki organlarında ağır metal birikimi ile sonuçlanır ve bu da bitkide zehirlenme ile ürün ve kalite kaybına sebep olur. Bu çalışmada, kadmiyum (Cd) ve potasyumun (K) birlikte etkisine karşı ayçiçeği *(Helianthus annuus L.)* bitkisinin tepkisi araştırılmıştır. Bu amaçla, potasyumun üç (0- 200 ve 400 mg kg^{-1}) ve kadmiyumun beş (0- 0,1- 0,3- 0,6 ve 1,2 mM) düzeyi toprağa uygulanmıştır. Sonuçlara göre artan Cd düzeyleri, ayçiçeği bitkisinde kök ve sürgünlerin kuru ağırlığı ve kök uzunluğu ile toplam klorofil (Chl) ve karotenoid (Car) içeriklerini azaltmış, ancak bu düzeyler yaprakların membran geçirgenliğini (MP) ve kadmiyumun toplam birikme oranını (TAR) artırmıştır. Potasyumun varlığında veya yokluğunda, sürgün ve kök Cd konsantrasyonu ve sürgün Cd alımı, Cd uygulamaları ile dikkate değer biçimde artmıştır. Ayrıca, uygulanan K dozları ile sürgün ve kökün her ikisinde de K alımını ve K konsantrasyonu önemli derecede artırmıştır.

Anahtar Kelimeler: Bio-akümilasyon, *Helianthus annuus* L., klorofil, kuru ağırlık, translokasyon

1. Introduction

Cadmium is one of the most toxic metallic elements for all living organisms. Although Cd is a non-essential element for plants, it is readily taken up by roots and could be accumulated by plant organs. Excess Cd in plants, especially in shoots, directly or indirectly affects some metabolic activities, such as inhibition of photosynthesis (Padmaja et al. 1990) and reduction of chlorophyll content (Azevedo et al. 2005; Dai et al. 2006; Mobin and Khan, 2007; Amirjani, 2012).

Generally, plants can tolerate low levels of Cd in soils, but high levels can cause toxicity symptoms, including growth reduction, leaf rolling,

and chlorosis (Benavides et al. 2005, Kabata-Pendias, 2011). In addition, root growth and cell division are typically inhibited by excess Cd (Barcelo et al. 1990). Moreover, uptake and translocation of essential nutrients (P, Ca, Mg, K) and use of water are generally reduced by excess Cd (Das et al. 1997; Zhang et al. 2002; Duman, 2012). When Cd ion enters from root surface, it can bind either to cell wall or pass through the plasma membrane using protein-like transporter (Wang et al. 2007) or via cation channels (like Ca^{2+}) (Clemens at al. 1998). Depending on the plant species, relatively high levels of Cd in rooting medium of plants tend to accumulate in the edible parts of leafy vegetables (Yang et al. 2009). The intracellular level of free Cd must be kept at a low level; otherwise protein conformation can change irreversibly by forming metal thiolate bonds (Liu et al. 2007). It can also cause alterations in cell wall and MP percentage (Ramos et al. 2002) due to reduction in water content (Costa and Morel, 1994).

Potassium is an important nutrient element that impacts a number of physiological and biochemical processes that are involved in plant resistance to biotic and abiotic stresses (Wang et al. 2013). Potassium has a key role in turgor regulation within the guard cells during stomatal movement (Marschner, 2012), in maintaining cell turgor and osmotic adjustment (Wang et al. 2013), and translocation of photo-assimilates for root growth (Römheld and Kirkby, 2010). It is also responsible for inhibiting the production of reactive oxygen species (ROS) during photosynthesis and NADPH oxidase (Cakmak, 2005) and Cd transportation and accumulation in soil-plant systems (Zhao et al. 2004). Moreover, monovalent cations like K^+ and Na^+ inhibit intracellular Cd uptake (Noraho and Gaur, 1995).

In agricultural lands, excessive use of fertilizers (especially phosphorus fertilizers) can result in Cd accumulation in soil and Cd toxicity in plants. This abiotic stress factor directly affects plant growth, crop yield, and quality (Bray et al. 2000). Sunflower chosen as the test plant is an oil seeded plant and has an important place in human food and animal feed. During growth period, it may be exposed to excessive fertilizing. Main objectives of this study were: (i) to determine the influence of high levels of Cd on visible growth parameters and photosynthetic pigments, (ii) to determine uptake, translocation, and accumulation of Cd by plant organs, and (iii) to investigate whether there is any interaction between K and Cd ions in sunflower plants.

2. Materials Methods

2.1. Experimental design

A greenhouse experiment with sunflower (*Helianthus annuus* L., cv. Sirena) for studying Cd and K relationships was carried out at Kocaeli University Arslanbey Campus in 2015 summer season (average air temperature 27/18 °C (day/night) and average relative humidity 62.7%). Sunflower seeds were sown into plastic pots containing 2000 g of air-dried soil. Before sowing, standard (healthy and equal-sized) sunflower seeds were surface sterilized in sodium hypochlorite (NaOCl) solution (0.2%, w/v) for 20 minutes, and then rinsed ten times with distilled water. Uniform seeds were soaked in tap water for 24 h, and then three seeds were sown to each pot. After emergence, they were thinned to one plant per pot. During the experimental period, soil was kept at approximately 70% of the field capacity.

Some properties of the experimental soil were as follows: loam texture (35.8% sand and 21.7% clay); pH (1/2.5 soil/water), 7.34; electrical conductivity (EC) in saturation extract, 0.51 dS m^{-1}; calcium carbonate equivalent ($CaCO_3$), 17.3 g kg^{-1}; organic carbon (Walkley-Black), 6.25 g kg^{-1}; and total nitrogen (N) (Kjeldahl), 0.86 g kg^{-1}. Ammonium acetate (NH_4OAc)-extractable K, Ca, Mg, and Na concentrations were 100, 2151, 124, and 64 mg kg^{-1}, respectively. Sodium bicarbonate ($NaHCO_3$)-extractable phosphorus (P) concentration was 12.4 mg kg^{-1} and hot water extractable-B was 1.64 mg kg^{-1}. Diethylene triamine penta acetic acid (DTPA)-extractable Fe, Mn, Zn, Cu and Cd were 24.3, 65.3, 2.09, 1.17, and 0.04 mg kg^{-1}, respectively. The soil properties were determined according to methods given in Page et al. (1982).

Five levels of Cd (0, 0.1, 0.3, 0.6, and 1.2 mM) as cadmium chloride ($CdCl_2$); three levels of K (0,

200, and 400 mg kg^{-1}) as potassium sulfate (K_2SO_4) were applied to the soil. The experiment set up in completely randomized design with factorial arrangement triplicates. For basal fertilization, nitrogen (N) and phosphorus (P) were applied to the soil at 150 and 75 mg kg^{-1}, respectively, as ammonium nitrate (NH_4NO_3) and ammonium dihydrogen phosphate ($NH_4H_2PO_4$). All these treatments were applied by spraying the solutions and mixing them into the soil.

2.2 Measurement and analyses

Sunflower plants were harvested 6 weeks after planting. Before the harvest, fresh leaf samples were taken out from the youngest fully expanded leaf for MP, Chl, and Car analyses. The fresh weight (FW) and dry weight (DW) of shoot and root were separately measured. The shoot samples were weighed for FW, washed with running tap water, and rinsed with distilled water. The root samples were taken out carefully, removed the soil particles, rinsed with distilled water, measured the lengths, and weighed for FW. Also, they were dipped in $CaCl_2$ solution (10 mM) for 10 minutes (Stold et al., 2003) in order to eliminate adsorbed trace elements from the root surface and then rinsed three times with cold distilled water. The shoot and root samples were dried at 70ºC, DW of the samples were quickly measured and subsequently ground to powder for nutrient element analysis.

The dried tissues were digested by dry-ashing method in a muffle furnace at 500°C for 6 hours and dissolved in 10 N HNO_3 (Miller, 2004). The concentrations of Cd, Zn, K, and Ca were determined by ICP-OES (Perkin-Elmer Optima 2100 DV). Nutrient uptakes of shoots and roots were calculated using the following formulation:

$$Cd/K\ uptake\ (\mu g/mg\ plant^{-1}) = [DW]_{shoot\ or\ root} \times [Cd/K\ concentration]_{shoot\ or\ root}$$

The BCF, TF and TAR were calculated by the following formulations (Ali et al. 2004; Shi et al. 2010):

$$BCF = [Cd]_{shoot\ or\ root} / [total\ Cd]_{soil}$$

where: $[\text{total Cd}]_{soil}$ = indigenous Cd concentration in the experimental soil + added Cd concentration

$$TF\ (\%) = 100 \times [Cd]_{shoot} / [Cd]_{root}$$

$$TAR\ of\ Cd\ (\mu g\ g^{-1}\ DW\ day^{-1}) = ([Cd]_{shoot} \times [DW]_{shoot}) + ([Cd]_{root} \times [DW]_{root}) / (growth\ day) \times ([DW]_{shoot} + [DW]_{root})$$

Membrane permeability (EC, %) for the shoot disc samples was measured by the electrical conductivity method as described by Yan et al. (1996). Photosynthetic pigments were measured in the youngest fully expanded fresh leaf samples before harvest. The fresh leaf samples (200 mg) were cut into small pieces and were homogenized in 10 mL of acetone (90%, v/v). The extract was then filtered and the absorbance of the extract was measured at 663, 645, and 470 nm using a spectrophotometer (Shimadzu UV/VIS-1201). The concentrations of Chl, and Car were calculated according to the formula given by Lichtenthaler (1987).

2.3. Statistical analysis

The statistical data in this study were analyzed by using Minitab 16 statistical package software program (Minitab Inc., 2010). The differences were compared by Duncan's multiple-range test (α=0.05). The levels of significance are represented by * at $P < 0.05$, ** at $P < 0.01$, and ns: non-significant.

3. Result and Discussion

3.1. Plant growth, membrane permeability and chlorophyll contents

The Cd is known as a toxic heavy metal element, and inhibits plant growth. In the absence and presence of K, shoot DW, root DW, and root length of sunflower tended to decrease with increasing Cd levels (Table 1). Regardless of applied K, in the applications of 0.3, 0.6, and 1.2 mM Cd, the shoot DW decreased significantly by 22.6%, 43.7%, and 79.5%, respectively, compared to control. While the root DW decreases were parallel to the shoot DW, only the highest Cd level caused a significant decrease in root length (30.9%), compared to control. These reductions may have been associated with Cd-phytotoxic effects on synthesis of cell wall (Barcelo et al. 1990). The concentration of Cd in shoot and root (Table 2) was higher than the threshold value of Cd

in insensitive plant species (5-10 mg kg^{-1}) defined by Kabata-Pendias (2011). Similar results were reported by Abd Allah et al. (2015) and Shi et al. (2010) for safflower, Shamsi et al. (2010) for soybean. Moreover, the interactions between Cd and K treatments have significant effect on MP, Chl and Car (Table 1). The MP increased with Cd applications in both control and K applications. Irrespective of K applications, the MP considerably reduced with increasing Cd applications. These increases in MP could be explained an alteration (Ramos et al. 2002) and interpreted with direct effect on membrane composition (proteins, lipids) or modification in lipid composition (Fodor et al. 1995). Moreover, the Chl and Car contents of sunflower leaves were reduced with increasing Cd additions. The reduction of Chl was by 40% in both 200 mg K kg^{-1} and 400 mg K kg^{-1} levels, whereas the reduction of Car was 39% in 200 mg K kg^{-1} and 31% in 400 mg K kg^{-1}, according to the control (Table 1). These results are consistent with high Cd levels inhibiting the formation of Chl (Azevedo et al. 2005; Mobin and Khan, 2007; Amirjani, 2012). High Cd, moreover, caused a significant reduction in chlorophyll and carotenoid contents in sunflower (Ducsay, 2011; Saidi et al. 2014; Abd Allah et al. 2015); and in fern (Dai et al. 2006). Reduction in chlorophyll content may be associated with the interference of metals with chlorophyll synthesis and lipid metabolism (Pandey and Tripathi, 2011). It can be also related to inhibition of root and shoot growth, photosynthesis, nutrient uptake, leaf area, etc. (Hameed et al. 2012). Additional K may also play a vital role in the formation of photosynthetic pigments and prevents Chl decompositions. These effects of K in plants could be associated with tolerance of plants to avoid abiotic stresses (Cakmak, 2005).

3.2. Concentration and uptake of Cd and K

Generally, the concentration and uptake of Cd depends on Cd treatment. Increasing Cd application significantly augmented the Cd concentration of shoot and root, and also Cd uptake of shoot under different K availabilities. Also, additional K enabled a significant decrease in Cd uptake and Cd leaf concentration (Table 2). Due to being a dominating factor of soil cation exchange capacity, K might have affected the transportation and accumulation of Cd in soil-plant system (Zahao et al. 2003). Moreower, monovalent cations (e.g., K^+ and Na^+) promoted non-competitive inhibition of intracellular Cd uptake (Shamsi et al. 2010). Our results showed that the Cd concentrations and uptake in roots were more than in shoots of sunflower (Table 2). Cataldo et al. (1981) reported that a large part of Cd accumulates in plant roots, and a relatively smaller portion of them was transported to the shoots. Sarma et al. (2006) revealed that the Cd concentration in descending order as: root>stem>leaves>fruits>seeds. The immobilization of Cd could be in roots by means of the cell wall to avoid Cd toxicity (Nishizono et al. 1989). Basically, metallic cations taken into the roots (e.g. Cd^{+2}) bound to cell wall and retained in the root (Greger, 1999) and only small amounts were let to translocate to the shoots (Hameed et al. 2012). Other reasons of Cd accumulation in roots might be associated with root selectivity against Cd ions and existing vacuoles in roots for storing excessive Cd (Hameed et al. 2012), and also existing heavy metal chelating peptides (phytochelatins) are known as an agent for Cd detoxification and shows plant tolerance (Buchanan et al. 2000).

The interaction between Cd and K on the shoot and root K concentrations and shoot K uptake was found non-significant, whereas it was significant in root K uptake (Table 2). Irrespective of Cd applications, the increasing K levels considerably enhanced the concentration and uptake of K in both shoot and root. But, irrespective of K applications, the highest Cd level decreased remarkably shoot K concentrations and shoots and root K uptakes, except for shoot K concentration, compared to control. Antagonistic effects between Cd and K were restricted the Cd and K uptake in shoot and root of sunflower (Wells and Brown, 1990; Das et al. 1997). Also, Zhang et al. (2002) and Duman (2012) reported that Cd ions inhibited nutrient uptake by affecting negatively cell membrane permeability.

Table 1. The mutual effects of K and Cd on some growth parameters, membrane permeability and photosynthetic pigments

Çizelge 1. *Ayçiçeği bitkisinde bazı büyüme parametreleri, membran geçirgenliği ve fotosentetik pigmentler üzerine potasyum ve kadmiyumun karşılıklı etkileri*

Treatments		Shoot DW	Root DW	Root length	MP	Chl	Car
K (mg kg^{-1})	Cd (mM)	(g pot^{-1})		(cm)	(%)	(µg g^{-1} FW)	
0	0	1.85	0.30	14.3	10.5 f	543 a	260 a
	0.1	1.65	0.25	16.5	16.4 cde	480 bc	223 de
	0.3	1.65	0.23	14.2	16.7 cd	383 e	188 g
	0.6	1.01	0.14	14.0	18. 5 bcd	313 f	160 h
	1.2	0.44	0.07	9.1	20. 5 b	208 h	104 j
200	0	1.87	0.27	15.7	14.2 e	450 cd	225 cd
	0.1	1.75	0.21	15.2	20.7 b	426 c	207 ef
	0.3	1.27	0.17	16.0	18.9 bc	390 e	201 fg
	0.6	1.09	0.19	14.1	16.9 cd	335 f	174 h
	1.2	0.39	0.06	11.6	26.6 a	272 g	143 i
400	0	1.98	0.29	14.6	16.1 de	498 b	250 ab
	0.1	1.81	0.27	16.3	16.8 cd	496 b	239 bc
	0.3	1.49	0.22	15.4	17.2 cd	323 f	171 h
	0.6	1.10	0.19	14.0	20.2 b	321 f	170 h
	1.2	0.32	0.06	10.3	nd	271 g	166 h
F-test		ns	ns	ns	***	***	***
0		1.32	0.20	13.6	16.5	385	187
200		1.27	0.18	14.5	19.5	375	190
400		1.34	0.21	14.1	14.0	382	199
F-test		ns	ns	ns	***	ns	**
	0	1.90 a	0.26 a	14.9 a	13.6	497	245
	0.1	1.73 a	0.27 a	16.0 a	18.0	467	223
	0.3	1.47 b	0.21 b	15.2 a	17.6	365	187
	0.6	1.07 c	0.17 c	14.0 a	18.5	323	168
	1.2	0.39 d	0.07 d	10.3 b	15.7	250	138
F-test		***	***	***	***	***	***

*The values in columns followed by different letters, where available according to F-test significance, are significantly different at $p < 0.05$. nd: No data, ns: non-significant, ** $p < 0.01$, *** $p < 0.001$. The values are the mean of three replicates. Means followed by the same letter in the same column do not differ significantly according to the Duncan's multiple range tests.*

Table 2. The mutual effects of K and Cd on the concentrations and uptakes of Cd and K in sunflower
Çizelge 2. *Ayçiçeği bitkisinde Cd ve K konsantrasyonları ve alımları üzerine potasyum ve kadmiyumun karşılıklı etkileri*

Treatments		Cd concentrations (µg g^{-1})		Cd uptake (µg $plant^{-1}$)		K concentrations (mg g^{-1})		K uptake (mg $plant^{-1}$)	
K (mg kg^{-1})	Cd (mM)	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
0	0	2.8 f	10.7 g	5.1 g	3.2	50.2	11.07	92.7	3.37 def
	0.1	24.6 ef	271.1 g	40.4 efg	69.0	51.0	6.93	83.7	1.80 ef
	0.3	57.2 e	660 f	93.8 cd	151.3	49.5	6.35	81.6	1.43 ef
	0.6	192 b	1699 c	192 a	238.9	50.6	7.57	50.3	1.07 f
	1.2	434 a	3371 a	190 a	241.1	55.7	4.28	24.4	0.33 f
200	0	6.4 f	10.0 g	12.1 g	2.13	70.5	23.7	132	5.00 cde
	0.1	11.3 f	264.8 g	19.8 fg	69.5	74.8	29.1	131	7.73 bc
	0.3	39.7 ef	887.1 ef	50.5 d-g	150.9	69.1	20.7	87.7	3.53 def
	0.6	130 c	1405 cd	139 b	266	69.6	21.2	75.7	4.03 def
	1.2	194 b	2540 b	75.4 cde	180	69.4	8.7	27.0	0.60 f
400	0	3.1 f	10.4 g	6.3 g	2.7	72.2	37.0	142	9.93 ab
	0.1	7.5 f	246 g	13.7 g	71.7	77.2	38.5	140	11.77 a
	0.3	28.9 ef	781 f	43.2 efg	174	74.8	41.2	112	9.07ab
	0.6	92.5 d	1127 de	102 bc	202	71.1	36.0	78.4	6.77 bcd
	1.2	203.8 b	2295 b	64.5 c-f	129	69.2	29.5	22.4	1.67 ef
F-test		***	***	**	ns	ns	ns	ns	*
0		142	1202	104	141	51.4 b	7.2 c	66.6 b	1.60
200		76.8	1021	59.3	134	70.7 a	20.6 b	90.6 a	4.18
400		67.2	891.7	45.9	116	72.9 a	36.4 a	99.0 a	7.84
F-test		***	***	***	ns	***	***	***	***
	0	4.11	10.3	7.81	2.69 d	64.3	23.9 a	122 a	6.10
	0.1	14.5	261	24.6	70.0 c	67.7	24.8 a	118 a	7.10
	0.3	43.0	776	62.4	159 b	64.5	22.7 a	93.8 b	4.68
	0.6	138	1410	144	236 a	63.8	21.6 a	68.2 c	3.96
	1.2	277	2735	110	183 b	64.8	14.2 b	24.6 d	0.87
F-test		***	***	***	***	ns	**	***	***

*The values in columns followed by different letters, where available according to F-test significance, are significantly different at p < 0.05. ns: non-significant, * p < 0.05, ** p < 0.01, *** p < 0.001. The values are the mean of three replicates. Means followed by the same letter in the same column do not differ significantly according to the Duncan's multiple range tests.*

3.3. Plant tolerance and bio-accumulation of cadmium

The BCF is used for evaluating the metal accumulation efficiency in plants. In the absence and presence of K, the shoot BCF was reduced significantly with increasing Cd applications. Irrespective of Cd applications, the shoot BCF at 200 mg K kg^{-1} level was 2-fold more than control (Table 3). Despite the effect of K fertilization was non-significant there was a K-induced tendency to increase in root BCF. The root BCF was greater than the shoot BCF. Han et al. (2007) explained this fact with Cd deposits in cell walls, in cytoplasm and on the inner surface of xylem vessel in the root tip of Iris plants. In our study, also both shoot and root BCF of sunflower was greater than critical level (BCF>1) for hyper-accumulator plants as accepted by Ma et al. (2001), and thus sunflower could be a Cd hyper-accumulator plant. McGrath and Zhao (2003)

reported that hyper-accumulators have a greater absorbance capacity (50-500-fold more) than normal plant, because of having root-to-shoot transport system and enhanced detoxification capacity. Lower Cd-BCF in shoot and root at higher levels was found for safflower (Shi et al. 2010) and *Eucalyptus camaldulences* (Gomes et al. 2012).

Table 3. The mutual effects of K and Cd on bio-concentration factor (BCF), translocation factor (TF) and total accumulation rate (TAR)
Çizelge 3. *Ayçiçeği bitkisinde biyo-konsantrasyon faktörü (BCF), translokasyon faktörü (TF) ve kadmiyumun toplam birikme oranı (TAR) üzerine potasyum ve kadmiyumun karşılıklı etkileri*

Treatments		Shoot	Root	TF	TAR
K (mg kg^{-1})	Cd (mM)	BCF	BCF	(%)	(%)
0	0	70 b	266	34.5 b	0.42
	0.1	2.17 c	24.10	9.17 cd	4.92
	0.3	1.70 c	19.60	8.70 cd	10.9
	0.6	2.83 c	25.27	11.5 bcd	12.0
	1.2	3.23 c	25.07	12.9 bcd	5.64
200	0	160 a	250	76.7 a	0.71
	0.1	1.00 c	23.53	4.30 d	4.32
	0.3	1.17 c	26.37	4.47 d	6.91
	0.6	1.93 c	20.90	7.63 cd	2.66
	1.2	1.47 c	18.87	9.33 cd	2.84
400	0	78 b	259	31 bc	0.49
	0.1	0.70 c	21.87	3.07 d	4.42
	0.3	0.87 c	23.23	3.70 d	9.05
	0.6	1.40 c	16.77	9.03 cd	9.66
	1.2	1.50 c	17.07	9.57 cd	1.79
F-test		***	ns	*	ns
0		16.0	72.1	15.3	6.78
200		33.1	68.0	20.5	5.49
400		16.6	67.5	11.2	5.08
F-test		***	ns	ns	ns
	0	103	259 a	47.3	0.54 d
	0.1	1.29	23.2 b	5.51	4.55 c
	0.3	1.24	23.1 b	5.62	8.96 b
	0.6	2.06	21.0 b	9.94	11.4 a
	1.2	2.07	20.3 b	10.0	3.42 c
F-test		***	***	***	***

*The values in columns followed by different letters, where available according to F-test significance, are significantly different at $p < 0.05$. ns: non-significant, * $p < 0.05$, *** $p < 0.001$. The values are the mean of three replicates. Means followed by the same letter in the same column do not differ significantly according to the Duncan's multiple range tests.*

The TF is a useful parameter for explaining the ability of plants to translocate a heavy metal from the roots to the shoots. In the absence and presence of K, TF of Cd was significantly decreased with increasing Cd applications. It was lower than 100% (the critical level). In the absence of Cd applications, the TF was 35% in control; it was significantly increased in 200 mg K kg^{-1} (77%), and decreased again with 400 mg K kg^{-1} (31%) (Table 3).The TF of Cd was higher in control applications than in increasing Cd levels. These findings may be explained by the immobilization of Cd in roots by phytochelatins and emerging of

metal accumulation, as reported by Shi et al. (2010) for safflower and De Maria et al. (2013) for sunflower.

The TAR expresses the absorption of heavy metal from the rooting medium. As shown in Table 3, the TAR of sunflower plant tended to increase as a function of increasing Cd treatments with and without K addition. Regardless of K levels, all Cd applications increased the TAR values. The maximum increase was found in the 0.6 mM Cd level (20-fold more than control). These results correspond to literature about sunflower and it could be associated with the reduction in shoot DW (Shi et al. 2010) and Chl contents (Ducsay, 2011; Saidi et al. 2014) and increasing Cd uptake depending on Cd addition in growth media.

4. Conclusion

It was concluded that increasing Cd levels caused a decreases in plant growth and photosynthetic pigments of sunflower plant due to its detrimental effects. Also, sunflower plant accumulated large amount of Cd in its roots and transported a smaller portion to its upper organs. It seems that it could capable to accumulate excess Cd in its roots to avoid effects of Cd toxicity. On the other hand, there was an antagonistic effect between Cd and K which led to decrease in uptake of root and shoot. Increasing Cd levels increased the K accumulation in the shoots and roots of sunflower, whereas increasing K levels decreased the Cd accumulation. Additional studies focusing on uptake, transport, and accumulation of Cd are needed to investigate mobilization into fruits and seeds and to determine interactions between Cd and other cations in soil and plant system for low Cd accumulation in agricultural production.

5. Acknowledgement

The abstract of this study was presented in "19th International Sunflower Conference (ISC)", held on 29th May-3rd June 2016, Edirne-Turkey, and the abstract was published in the Congress' book.

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