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Effects of full and limited irrigation and contaminated soil on cadmium uptake by corn

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Abstract

Using plants for the remediation of soils contaminated with heavy metals is an economical, cheap, and effective strategy. The goal of this research was to study the effect of sewage sludge and drought stress on the remediation of cadmium in soil, root uptake by corn plant. This study was carried out on corn in factorial design experiment based on completely randomized design with three replications in three soil pollution levels, namely B1 (control soil), B2 (Cd with soil, 20 mg.kg^{-1}), B3 (Cd with sewage sludge with soil treated, 20 mg.kg^{-1}), and two different irrigation regimes, including A1 (full irrigation) and A2 (limited irrigation). The research included two irrigation treatments at two levels of irrigation: 100% of field capacity (A1) and deficit irrigation at 80% of field capacity (A2). The results showed that the soil treated with cadmium and sewage sludge decreased dry and fresh wet weight plant. Sewage sludge increased the amount of cadmium concentration in shoot almost 21% toward the soil treated with cadmium (soil without cadmium); however, it could not increase cadmium uptake due to the decrease in shoot and root dry matter. In limited irrigation, cadmium concentration in shoot and root was reduced by 46 and 16% toward control treatment, respectively. With increasing irrigation and in the soil treated with sewage sludge, the transfer factor of cadmium from root to shoot dry matter increased. The translocation factors were 0.65, 0.5, and 0.13 for sewage sludge contaminated treatments, cadmium-contaminated treatments, and control treatments, respectively. Based on the results, growing plants at an irrigation level of 100% offered nest advantages in terms of higher biomass and efficient Cd removal.

Keywords: Accumulation; Corn; Drought Stress; Sewage sludge; Soil pollution

1. Introduction

Heavy metals are hazardous to humans and other life forms, and their presence in the environment can cause soil and water pollution (Bello *et al*., 2018). Phytoremediation is a plant-based technology which utilizes plant species to reduce or limit the transfer of pollutants into land and water sources (Muthusaravanan *et al*., 2018). Sewage sludge contains essential nutrients able to promote plant growth. Meanwhile, considerable amounts of heavy metals and high pH level in sewage sludge increases the amount of extracted and soluble heavy metals in soils containing sewage sludge (Zhang *et al*., 2017; Antolin *et al*., 2005). Heavy metal absorption by soil through plants depends on the type and concentration of heavy metal in soil, mobilized and bioavailability of metals, water content of soil, and plant species (Thakur *et al*., 2016). In general, the availability of heavy metals relies on their physical, chemical, biological properties and their interaction such as soil texture, structure, permeability, organic material content, clay content, root system, calcium carbonate, oxidation-reduction potential, pH, salt, solubility, and concentration (Ali *et al*., 2004).

Gu *et al*. (2013) investigated the effect of soils treated with sewage sludge on the absorption of heavy metals and growth of ryegrass during the germination stage. Their results demonstrated that sewage sludge treatment increased the availability of metals in the soil, thereby augmenting the accumulation of these metals in the plant. Indeed, their findings

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indicated the increment in metal concentrations (Cd, Ni, Cu, Zn, Cr, Mn) in root and aerial parts of sewage sludge treatments compared to the control treatment. Cadmium is significantly adsorbed by soil particles; thus, it is expected that slight changes in soil moisture will not have significant effect on the bioavailability of this metal (Van Gestle and Van Diepen, 1997). However, the amount of extractable heavy metals increases by the rise in soil water content and the accumulation of heavy metals in plant (Onder *et al*., 2016; Angle *et al*., 2003). Generally, the adsorption and extraction of cadmium in soil is dependent on certain factors, one of which is soil water content; the more the soil moisture, the more the availability and adsorption of cadmium (Laegreid *et al*., 1999). Onder *et al*. (2016) demonstrated the ability of *Brassica* to remove Pb from the soil at four different levels of irrigation and doses of lead. The results of their study showed that higher irrigation levels increased the amounts of Pb^{2+} removed from the soil. Their findings further showed that higher irrigation levels resulted in higher biomass and efficient Pb removal.

Angel *et al*. (2003) reported the effect of soil water content on heavy metal adsorption via three super absorbents of nickel and zinc plants, namely *Thlaspi*, *Alyssum*, and *Berkheya*. Their results showed that the extractable Ni content of soil decreased with the increase in soil water content. The amount of generated biomass in all plant species and the accumulated metals in the plants increased at high water content. The highest concentrations of Zn and Ni in the leaf were also detected at high water content. Therefore, the present study was carried out to investigate the effect of deficit irrigation, cadmium concentration in soil and soil contaminated with sewage on cadmium absorption by corn plant. Natasa Mirecki *et al*. (2015) in a study titled “Transfer factor as indicator of heavy metals content in plants”, showed that transfer factor for Cd in all samples control plants was 0.01-0.1 while in the polluted area, the TF was found to be between 0.1 and 0.5. Their results revealed significant variations in the transfer factor of Cd compared with other metals in both locations. The TF value for Cd (0.01-2.0) was quite high compared to Pb (0.001-0.2).

2. Materials and Methods

This study was performed in a completely randomized design (RCBD) with a factorial experiment during a crop season in 2014 in the Water Research Laboratory of Irrigation and Rehabilitation department at the Agricultural and Natural Resources Campus of University of Tehran, Karaj, Iran. The research included two irrigation treatments at two levels, including irrigation at 100% field capacity (A1) and deficit irrigation at 80% field capacity (A2) (Onder *et al*., 2016; Angle *et al*., 2003). We also used three levels of soil contamination, namely soil without contamination (B1), soil contaminated with 20 mg/kg of cadmium (B2) (Hammami *et al*., 2018), and soil contamination with sewage (using an agricultural soil irrigated with sewage for several crop seasons); however, because the soil treatment analysis indicated low levels of cadmium contamination, this soil was artificially contaminated by 20 mg/kg of cadmium and mixed with a field soil through a mass ratio of 1:1 (B3). Maximum permissible concentration of cadmium in soil was 1 to 3 mg/kg (Delgado *et al*., 2017; Nicholson *et al*., 2003).

The study was conducted in three replicates and on a total of 18 samples. The tested soil was prepared from a research farm at Tehran University and then passed through 2 mm sieves. Basic soil properties, such as soil texture (Bouyoucos, 1962), pH (Carter and Gregorich, 2008), EC (Rhoades, 1996), total nitrogen (Bremner, 1996), P (Olsen *et al*., 1954), K (Hemke and Sparks, 1996), OC% (Walkley and Black, 1934), Zn, Cu, Ni, and Pb concentration (Page, 1982), and extractable Cd with DTPA (Lindsay and Norvell, 1978) were also measured. Soil was contaminated with cadmium through the use of cadmium nitrate salt (Cd(NO3)2.4H2O) (Sooksawat *et al*., 2013) which was sprayed all over the soil (Hammami *et al*., 2018; Huang *et al*., 2009). Sewage-contaminated soil was prepared from a sewage irrigated soil in Rasht, Iran; after air-drying and passing through a 2 mm sieve, soil properties were measured by the mentioned methods. Next, the sewage-contaminated soil was added to the field soil in a mass ratio of 1:1 and completely mixed.

In order to achieve ionic balance, the contaminated soil was transferred to plastic bags without drainage and incubated for two weeks under greenhouse conditions at 20° C temperature and 53% relative humidity. This was done until the interaction of the pollutants and soil evolved and the contamination conditions become more natural. The maize (Zea mays) hybrid variety Single Cross 704 (SC704) was used. The maize hybrid variety single was selected due to its high yield tolerance to drought stress and short seasonal cultivation duration. At the end of the growing season, the samples (root and aerial parts) were taken to laboratory; after washing with distilled water, they were oven dried, milled, and extracted, and cadmium concentration in plant extracts was measured by atomic absorption spectrometer of Shimadzu-670 model (Anjum *et al*., 2008). The absorption amount was calculated through multiplying the cadmium of concentration of shoot in plant dry matter (Bianconi *et al*., 2013). To assess the ability of plants to accumulate Cd in their organs, translocation factor (TF) was used (Eq. 1) (Aman *et al*., 2018). The averages were compared via Duncan new multiple range (DNMRT) using SAS version 9.2 (SAS Institute Inc., 2007); *P*-values $\leq$ 0.01 were considered as statistically significant, and the corresponding graphs were drawn with Excel.

$$TF = \frac{\text{Heavy metal concentrations in the shoot (mg/kg)}}{\text{Heavy metal concentrations in the root (mg/kg)}} \quad (1)$$

3. Results and Discussion

Based on this experiment result, the soil was classified as clay loam with an appropriate pH for plant growth and low salinity (table 1). It had low levels of Cd and seemed to be suitable for the exposed treatments. Table 2 shows certain physical and chemical parameters of sewage sludge used in this study.

Table 1. Physicochemical characteristics of experimental soil

Characteristics	Contents
Texture	Clay loam
pH	7.80
EC (dS/m)	1.50
N total (%)	0.11
P (mg/kg)	76.00
K (mg/kg)	520.00
OC (%)	0.72
Calcium carbonate equivalent (%)	10.50
Cd (mg/kg)	0.13

Table 2. Sewage sludge decomposition results

Parameter	Sewage sludge before mixing with soil
pH	8.10
EC (dS/m)	1.70
Cd (mg/kg)	0.40
Zn (mg/kg)	1.87
Cu (mg/kg)	2.47
Ni (mg/kg)	1.59
Pb (mg/kg)	1.83

Table 3. Maximum allowable concentration (MAC) in soil (Iranian Environmental protection Agency Iran, 2014)

Parameter	MAC value (mg kg-1)
Cd	1
Zn	200
Pb	100
Cu	75
Ni	40
Cr	75
Co	30

Tables 4 and 6 present the effect of soil pollution and irrigation levels on the fresh and dry weights of shoots and roots of corn. During the experimental period with sewage sludge, the fresh weight of aerial parts was reduced from 140.22 gr in control treatment to 127.57 gr in sewage sludge contaminated treatment. The dry weight of aerial parts also decreased by 12.6% from 23.5 gr in the control treatment to 20.53 gr in the treatment with sewage sludge.

Addition of cadmium and sewage sludge to soil, significantly reduced the fresh weight of aerial parts. The same trend was observed in the root, so that the fresh weight of corn root in the control treatment was 71.91 gr while it decreased to 65.73 gr in cadmium treatment and 18.58 gr in the sewage sludge treatment. The root dry weight was diminished by 10.8% in sewage treatment compared to the control treatment. This decline in plant yield could be attributed to the high concentrations of heavy metals in sewage sludge, causing plant stress and disrupting plant growth. The heavy metals in soil reduced plant growth, biomass, and photosynthesis (Tauqeer *et al*., 2016).

The accumulation of cadmium in plants led to deficiency in Fe, Mg, and Ca, thereby significantly reducing the growth rate and photosynthesis (Mobin and Khan, 2007). Kang *et al*. (2010) showed that with the increase in the salinity of irrigation water, seedling biomass, plant height, and fresh and dry weight of waxy maize were reduced by 2%; furthermore, the fresh weight yield decreased by 0.4-3.3% per every 1dS/m. Given these results, it can be concluded that the decrease in the amount of irrigation water significantly reduced the fresh and dry weights of the plant. With decreasing the amount of irrigated water, the fresh and dry weights of the aerial parts were reduced by 18.83% and 17%, respectively, compared to the control treatment. Moreover, root fresh weight increased from 75.79 gr in full irrigation treatment to 50.6 gr in deficit irrigation treatment. The presence of moisture in the root area made it possible to further develop the roots for the absorption of nutrients and water, thereby lowering plant weight reduction under such conditions. In addition, photosynthesis, an important physiological process in plants, decreases by water deficit (Hernandez-Santana *et al*., 2017). The irrigation water content applied to the treatments varied from 13 litres in limited irrigation and soil contaminated with cadmium and with sewage to 27 litres in full irrigation and non-polluted soil.

Table 4. Comparison of the main and intermediate effects of soil pollution and irrigation levels on fresh and dry weights of corn aerial parts

Soil pollution levels	Irrigation levels		
	A1	A2	Average
	Fresh weight of plant aerial parts (gr)		
B1	155.37 a	125.07 bc	140.22
B2	153.00 a	117.53 c	135.26
B3	136.60 b	118.57 c	127.58
Average	148.32	120.39	134.35
	Dry weight of plant aerial parts (gr)		
B1	26.87 a	20.13 a	23.50
B2	24.87 a	21.50 a	23.18
B3	21.70 a	19.37 a	20.53
Average	24.48	20.33	22.40

* Means with different alphabets in the same column according to severity level are significantly different at $p < 0.01$. (A1: irrigation at 100% of FC, A2: irrigation at 80% of FC, B1: soil, B2: soil with Cd, B3: soil with Cd and sewage sludge)

Table 5. Comparison of the main and intermediate effects of soil pollution and irrigation levels on fresh and dry weights of corn roots

Soil pollution levels	Irrigation levels		
	A1	A2	Average
	Fresh weight of plant aerial parts (gr)		
B1	85.03 a	58.80 c	71.91
B2	80.30 ab	50.57 cd	65.43
B3	73.93 b	42.43 d	58.18
Average	79.75	50.60	65.17
	Dry weight of plant aerial parts (gr)		
B1	23.40 ab	19.83 bc	21.61
B2	24.67 a	18.47 c	21.57
B3	21.27 abc	17.30 c	19.28
Average	23.11	18.53	20.82

* Means with different alphabets in the same column according to severity level are significantly different at $p < 0.01$. (A1: irrigation at 100% of FC, A2: irrigation at 80% of FC, B1: soil, B2: soil with Cd, B3: soil with Cd and sewage sludge)

Table 5 indicates the significant impact of soil contamination and irrigation water amount treatments on cadmium concentration in the shoot and root. As observed, with the reduction in the amount of irrigation water, cadmium concentration in corn shoots and roots was reduced by 46% and 16%, respectively. In other words, cadmium concentration, which was 7.42 mg/kg of dry matter in the shoots of full irrigated treatment, was reduced by 46% to 4.5 mg/kg in deficit irrigation treatment. As seen, with increasing the cadmium concentration in soil, it also increased significantly in the plant because with the presence and abundance of each element in the root environment, provided that the element is absorbable, it increases concentration in the plant, such that this increase is 98.5% in shoots and 94.5% in roots. If in addition to cadmium, there was also sewage sludge in the soil, cadmium concentration in plant aerial parts increased by 21% compared to cadmium-contaminated soil. Addition of sewage sludge to soil augmented the salinity due to the high concentrations of elements such as chlorine and sodium. The increased salinity reduced the acidity of soil, thereby raising the concentration of cadmium in the shoots and roots of the plant. Soil acidification increased the phytoavailability of Cd in the soil and the accumulation of Cd in plants (Zhu *et al*., 2016); therefore, via adding sewage sludge to soil and reducing soil acidity, the cadmium uptake in the plant is expected to increase, a trend which also occurred in the present study.

Table 6. Comparison of the main and intermediate effects of soil pollution and irrigation levels on cadmium concentration in corn roots and shoots

Soil pollution levels	Irrigation levels		
	A1	A2	Average
	Cadmium concentration in shoots (mg/kg dry matter)		
B1	0.12 e	0.10 e	0.11
B2	9.82 b	5.26 d	7.54
B3	12.31 a	6.80 c	9.55
Average	7.42	4.05	5.74
	Cadmium concentration in roots (mg/kg dry matter)		
B1	0.80 c	0.83 c	0.81
B2	16.23 a	13.74 b	14.85
B3	16.07 ab	13.47 b	14.77
Average	11.03	9.26	1.00

* Means with different alphabets in the same column according to severity level are significantly different at $p < 0.01$. (A1: irrigation at 100% of FC, A2: irrigation at 80% of FC, B1: soil, B2: soil with Cd, B3: soil with Cd and sewage sludge)

The amount of cadmium absorption in the corn shoot and root was obtained by multiplying the cadmium concentration in the dry matter weight of the plant. Table 6 shows the effect of irrigation treatment on cadmium uptake in the plant. According to the results of Table 6, with decreasing the irrigation water, cadmium absorption by plant shoots and roots decreased by 53% and 34%, respectively. It was also observed that the reduction in irrigation water decreased cadmium concentration in the plant; on the other hand, because high moisture increases plant biomass, it also increases the absorption of heavy metals in the plant (Onder *et al*., 2016; Angle *et al*., 2003). Similar to cadmium concentration in soil contamination treatment, with increasing cadmium levels in soil, cadmium uptake significantly increased in the plant (Table 7). According to the results of Table 6, cadmium uptake by root in the sewage sludge treatment (324.52 mg per pot) was 11% less than cadmium-contaminated treatment (288.14 mg per pot). This is ascribed to the dry weight loss of the plant in this situation. However, in the shoots, despite the dry matter weight loss of sewage sludge treatment, the cadmium uptake increased by 12% due to the increase in cadmium concentration. Belhaj *et al*. (2016) showed that sewage sludge application increased the Pb, Ni, Cu, Cr, and Zn concentrations of soil, thereby increasing the absorption of these elements by the plant.

Table 7. Comparison of the main and intermediate effects of soil pollution and irrigation levels on cadmium uptake in corn roots and shoots

Soil pollution levels	Irrigation levels		
	A1	A2	Average
	Cadmium uptake in shoots (mg/pot)		
B1	3.25 c	2.10 c	2.67
B2	243.90 a	111.73 b	177.81
B3	267.55 a	129.31 b	198.43
Average	171.57	81.05	126.30
	Cadmium uptake in roots (mg/pot)		
B1	18.55 c	16.56 c	17.55
B2	400.17 a	248.87 b	324.52
B3	339.04 a	237.25 b	288.14
Average	252.59	167.56	210.07

* Means with different alphabets in the same column according to severity level are significantly different at $p < 0.01$. (A1: irrigation at 100% of FC, A2: irrigation at 80% of FC, B1: soil, B2: soil with Cd, B3: soil with Cd and sewage sludge)

Onder *et al*., (2016) investigated the effect of different irrigation levels on the adsorption of nickel by *Tagetes*. Generally, the level of Ni removal by the plants decreased with the increase in water stress. Angel *et al*. (2003) investigated the effect of soil moisture on the adsorption of zinc and nickel by three superabsorbent plants. In general, at higher moisture content, the amount of accumulated metals in the plant was increased in all species.

These results indicate that the plants had proper growth under good moisture conditions and continued to hyper accumulate metals, which is consistent with the results of this study.

Azizian *et al*. (2013) investigated the relationship of corn with cadmium contamination and drought. They concluded that under high soil moisture conditions, the dry matter production of the shoot and cadmium uptake by plant increased.

Translocation factor (TF) indicates the ability of plants to tolerate and accumulate heavy metals in their organs. This parameter was calculated using the ratio of metal concentration in the shoots to that in the roots (Thakur *et al*., 2016). According to this definition, cadmium translocation factor is cadmium concentration in the shoots divided by that in the roots. During plant uptake, in addition to plant capacity for accumulation, the transfer of elements from root to shoot should be considered. Fig. 1 shows the cadmium translocation factor from the roots to the shoots of corn, which is affected by irrigation water. As observed, with the reduction in irrigation water from full field capacity to 80% field capacity, the translocation factor decreased by 34%. In fact, with increasing the soil moisture, more cadmium was transferred from the root to the shoot.

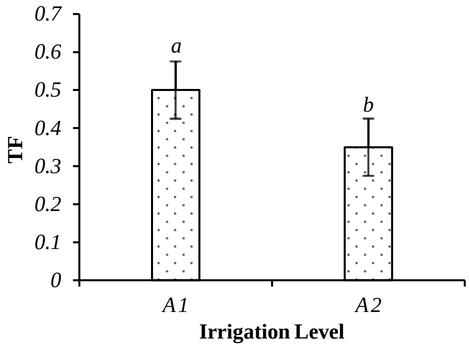

Fig. 1. Comparison of cadmium average translocation factor in two irrigation treatments: A1: irrigation at 100% of FC, A2: irrigation at 80% of FC. Different letters indicate that values are significantly different at P< 0.01

Also, with the increase in cadmium levels, the cadmium translocation (from roots to shoots) factor increased. To put it otherwise, by increasing the concentration of cadmium in the soil, the translocation of this metal from root to shoot increased by 74% from 0.13 in the control treatment to 0.5 in the cadmium contaminated treatment. According to Fig. 2, the translocation factor, regarding the soil contaminated with both sewage and cadmium, increased compared to the control and cadmium treatments. The translocation factors were 0.65, 0.5, and 0.13 for sewage sludge, cadmium, and control treatments, respectively. Taken together, the use of sewage sludge causes the accumulation of heavy metals in the soil, and the higher the amount of these elements in the soil, the higher the absorption by plant will be. Natasa Mirecki *et al*. (2015) in a study titled “Transfer factor as indicator of heavy metals content in plants”, showed that the transfer factor of Cd in all samples of the control plants was 0.01-0.1 whereas in the polluted area, the TF was found to be between 0.1and 0.5. Their results revealed a significant change in the transfer factor of Cd compared with other metals in both locations. The TF value of Cd (0.01-2.0) was quite high in comparison to Pb (0.001-0.2). There exists a good agreement between the present research and that of Natasa *et al*. (2015) regarding cadmium transfer factor (TF) in soil pollution.

4. Conclusion

By increasing cadmium content in the soil, its concentration in the shoots and roots of the corn increased by 98.5% and 94.5%, respectively, but the dry weights of the shoot and root were reduced. Adding sewage sludge to the soil also increased the concentration of cadmium in the plant; however, it decreased plant productivity, which in turn reduced the cadmium uptake by the plant. The amount of absorbable cadmium in soil at the beginning of the experiment ranged from 5.97 mg to 8.17 mg in different treatments, reaching 5.08 to 7.02 mg after the tests. The maximum cadmium content in the shoot and root was 0.436 mg Accordingly, in the sewage sludge treatment, the amount of cadmium uptake by the root decreased by 11%. In fact, sewage sludge augments cadmium solubility in the soil and cadmium concentration in the plant through increasing soil salinity and reducing acidity. Reduced irrigation water led to a reduction in the concentration of cadmium in the shoots and roots by 46% and 16%, respectively; it also reduced the fresh and dry weights of these parts. The TF value of Cd (0.01-2.0) was significantly higher than Pb (0.001-0.2).

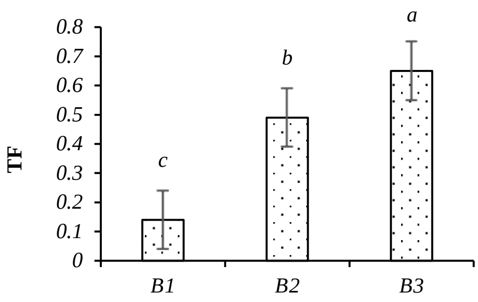

Fig. 2. Comparison of cadmium translocation factor in soil pollution treatments. B1: soil, B2: soil with Cd, B3: soil with Cd and sewage sludge. Different letters indicate that values are significantly different at P< 0.01

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