Response of Corn to Cadmium and Drought Stress and Its Potential Use for Phytoremediation

A. Azizian1*, S. Amin1, M. Maftoun2, Y. Emam3, and M. Noshadi1

ABSTRACT

In the present study, the effects of different cadmium (Cd) levels of irrigation water (0, 5, 10 and 20 mg L−1) on corn plants (foliage) under different irrigation intervals (1, 3, and 7 days) were investigated. Clear Cd toxicity symptoms appeared on the plants at the end of the experiment. The results showed that stem dry weight (DW) followed by transpiration (T) and plant height were the measured plant parameters most sensitive to increasing Cd levels of irrigation water. In addition, Cd reduced water uptake by corn and led to more soil moisture. The results also demonstrated that corn might produce more shoot biomass with Cd application, which should be taken into consideration if no visible symptoms of Cd toxicity and considerable amounts of the metal uptake are present. Cadmium application through irrigation did not show a marked impairment in the nutrient status of the plants. Moreover, accumulation of Cd in the leaves was more than the stems by 24, 56, and 27% at 1, 3, and 7-day irrigation frequencies, respectively. Also, corn stem was found to be more sensitive to Cd than leaf. The results showed that corn might be used for phytoremediation of Cd under optimum moisture conditions and light contamination of the soil. Furthermore, shoot Cd concentration followed an asymptote pattern as a function of soil Cd, which was expressed by a plateau-type model under each irrigation interval.

Keyword: Cadmium, Corn, Drought, Phytoremediation, Stress.

INTRODUCTION

Water availability for irrigation has become a major issue for agriculture in arid regions. Consequently, wastewater reuse has attracted public attention as an alternative water source. There are numerous reports on the application of wastewater to agronomic crops, rangelands, forests, and recreation areas in the literature. Land application of wastewater also has the advantage of recycling nutrients and organic matter and protecting fresh water resources owing to a reduction in the discharge of wastewater (Saucedo et al., 2005). However, the uncontrolled use of wastewater in agriculture has potential health implications for consumers. Studies have documented adverse animal and human health effects resulting from the use of untreated or inadequately treated wastewater in agriculture. Also, the effluent of wastewater treatment plants generally contains high levels of microorganisms and various heavy metals (Grifferty and Barrington, 2000; Toze, 2006). A principle drawback of irrigation with treated wastewater is the potential heavy metal accumulation in soil and feedstuff which may cause health risks both to animals and humans (Dikinya and Areola, 2010).

Cadmium is a heavy metal whose presence in the environment is of great concern, because of its toxicity to living
organs. Cadmium inhibits the plant root and shoot growth and yield production, affects plant nutrients uptake and homeostasis and reduces its water uptake (Rascio et al., 1993). This unwarranted plant element is taken up by roots and translocated to aerial organs of feed/food crops, entering the food chain with a significant potential to impair animal and human health (di Toppi and Gbrielli, 1999; Tyler and McBride, 1982). Corn is an important food and feed crop, capable of accumulating Cd in its shoot (Walker et al., 1977 and Sameni et al., 1987). Corn has potential in phytoremediation, whereby metal accumulating plants are used to remove toxic metals from soil and water (Chaney et al., 1998). In the present study, the response (agronomic behavior and chemical composition) of the plant to different Cd levels of irrigation water under water stress conditions and its potential for Cd phytoremediation were investigated. Shoot tissue Cd concentration model was also studied.

**MATERIALS AND METHODS**

A bulk sample of the top layer (0-20 cm) of a calcareous silty clay soil (fine, mixed, mesic, Typic calcixerepts) was collected from an uncultivated field at Bajgah Agricultural Experiment Station, 16 km north of Shiraz, Fars Province, I. R. of Iran. The soil was then air-dried and passed through a 2 mm sieve (some of its physico-chemical properties are shown in Table 1). The soil was mixed uniformly with 150 mg N kg⁻¹ as urea, 50 mg P kg⁻¹ as KH₂PO₄, 5 mg Fe kg⁻¹ as Fe-EDDHA and 5, 10 and 5 mg kg⁻¹ Zn, Mn and Cu, respectively as their sulfate salt. The pots were filled with 6 kg of treated soil. The Van Genuchten Model (Van Genuchten, 1980) for soil moisture retention curve was determined using hanging water column and pressure plates apparatus in order to convert the soil moisture to the corresponding matric potential.

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Amount/type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (%)</td>
<td>14.1±0.50</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>40.4±0.21</td>
</tr>
<tr>
<td>Texture</td>
<td>Silty clay</td>
</tr>
<tr>
<td>Field capacity</td>
<td>21.64±0.55</td>
</tr>
<tr>
<td>Bulk density</td>
<td>1.42±0.11</td>
</tr>
<tr>
<td>OM (%)</td>
<td>1.1±0.05</td>
</tr>
<tr>
<td>Soil pH (paste)</td>
<td>7.84±0.21</td>
</tr>
<tr>
<td>CEC (cmole kg⁻¹)</td>
<td>14.1±0.50</td>
</tr>
<tr>
<td>ECₑ (dS m⁻¹)</td>
<td>0.50±0.11</td>
</tr>
<tr>
<td>Background Cd (mg kg⁻¹)⁶</td>
<td>0.31±0.09</td>
</tr>
</tbody>
</table>

⁶ Mean±SD (n= 3), ⁷ DTPA extractable.

The seeds of corn (*Zea mays* L., *cv* single cross 704) were planted in pots in a glasshouse under natural light with average day and night temperatures of 36° and 11°C, respectively. Each pot was irrigated with distilled water to near field capacity by weight, for 15 days after planting. Then, corn was thinned to 3 plants per pot and irrigated with different Cd concentration at 1, 3, and 7 day intervals (common intervals for investigation of the moisture treatments (wet to dry) on corn plant under glasshouse conditions in the study area). Irrigation was done by raising the soil moisture to near field capacity by weight. The amounts of applied water were regarded as representative of evapotranspiration (ET), since no water was lost by drainage. The Cd levels of irrigation water were 0, 5, 10 and 20 mg L⁻¹, obtained by adding CdCl₂·H₂O to the distilled water. These levels were selected to represent reasonable amounts of Cd in raw wastewater (according to Shayegan and Afshari (2004), the maximum Cd in raw wastewater reported in Iran is 0.75 mg l⁻¹) and to insure that considerable amounts of applied Cd remained available for plant uptake. The experimental design was completely randomized design with three replications. In order to measure evaporation, pots without plants were used in each treatment. Irrigation and Cd treatments were continued for 75 days after planting.
At harvest (plants were harvested as fodder), the above-ground sections of the plants were cut at the soil surface and separated to stem and leaf. The harvested plant materials were washed with tap and then with distilled water, dried to a constant weight at 65°C, weighed and ground with an electric mill to pass a 40-mesh screen. Representative samples were dry-ashed at 550°C for 4 hours, extracted with 2M HCl, filtered through Whatman No. 42 filter paper and analyzed for Cd, iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) by an atomic absorption spectrophotometer (model Perkin Elmer 4110), potassium (K) by flame photometer (model Ciba-Corning 400) and phosphorous (P) by using the blue ammonium-molybdate method with spectrophotometer (model Jenway 6405 UV/Visible) at 880 nm.

The total transpiration (T) was obtained by cumulative applied water minus cumulative evaporation. Water use efficiency (WUE) was calculated as the ratio of shoot dry weight (DW) to total volume of ET:

\[
WUE = \frac{DW (g)}{ET (l)} \tag{1}
\]

The efficiency of the plant parts for phytoremediation was evaluated by means of bioconcentration factor or \( BCF \); the ratio of Cd concentration \( C \) in plant to Cd concentration in the soil as:

\[
BCF = \frac{C_{\text{Plant}}}{C_{\text{Soil}}} \tag{2}
\]

In addition, the translocation of Cd within the plants shoots was investigated by calculating the translocation factor (TF) as:

\[
TF = \frac{BCF_{\text{Shoot}}}{BCF_{\text{Root}}} \tag{3}
\]

Moreover, cadmium uptake was calculated by multiplying stem and leaf DW and their Cd concentrations. Hence, the apparent Cd recovery, i.e.:

\[
\text{apparent Cd recovery} (\%) = \left( \frac{(Cd \text{ uptake})_T - (Cd \text{ uptake})_C}{(Soil \text{ accumulated Cd})_T} \right) \times 100 \tag{4}
\]
Figure 1. Effect of irrigation interval and irrigation water Cd levels, on corn growth parameters: (a and c) Plant height, leaf number and stem and leaf dry weight (DW), (b and d) Leaf area (LA), transpiration (T) and evapotranspiration (ET). Means within each plant parameter followed by the same letter are not statistically different at $P \leq 0.05$.

Cd treatments on plant height, leaf DW, and ET of the corn plant. Increasing Cd levels, even up to 20 mg L$^{-1}$, had no significant effect on these growth parameters under water stress conditions, while at other irrigation regimes a significant reduction occurred with 10 or 20 mg Cd L$^{-1}$.

The mean matric potentials which the plants experienced in their growing period are summarized in Table 5. As expected, the maximum soil matric potential (i.e. minimum soil water depletion) occurred at the 1-day irrigation interval. Moreover, greater Cd levels resulted in higher soil matric potentials which are compatible with ET and T rates at each irrigation frequency.

Table 2. Interaction effects of irrigation intervals and Cd levels of irrigation water on corn height, leaf dry weight and ET.

<table>
<thead>
<tr>
<th>Irrigation interval (d)</th>
<th>Cd level of irrigation water (mg L$^{-1}$)</th>
<th>Plant height (cm)</th>
<th>Leaf dry weight (g pot$^{-1}$)</th>
<th>ET (10$^{-3}$ m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>120.0a$^a$</td>
<td>116.0a</td>
<td>98.3b</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>66.0c</td>
<td>63.0c</td>
<td>48.7d</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>20.8e</td>
<td>20.3e</td>
<td>18.5e</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>36.5a</td>
<td>37.0a</td>
<td>33.1ab</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>18.1c</td>
<td>16.7cd</td>
<td>13.4de</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>6.5fg</td>
<td>6.5fg</td>
<td>6.1fg</td>
</tr>
<tr>
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<td></td>
<td>14.56a</td>
<td>13.95a</td>
<td>12.41b</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>9.16c</td>
<td>9.11c</td>
<td>8.71c</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>7.27d</td>
<td>7.26d</td>
<td>7.01d</td>
</tr>
</tbody>
</table>

$^a$ Means within each plant parameter followed by the same letter are not statistically different at $P \leq 0.05$. 

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In other words, Cd reduced water uptake by corn and led to more remaining moisture of the soil. Barcelo et al. (1988) also reported reduced water uptake by Cd-treated bush bean plants. In the present study, Cd levels had no significant effect on the WUE (data not shown). In general, corn had greater WUE in the 1-day irrigation interval. The plants had slightly higher WUE when treated with Cd at 1 and 7-day irrigation frequencies as compared with the control. This means that with a given volume of effluent supply, corn produces more shoot biomass with Cd application. This is important in feed production if no visible symptoms of Cd toxicity appear and plants take up a considerable amount of the metal. There are some evidence in the literature indicating that the growth of plants exposed to low Cd levels might be stimulated (Kirkham, 1978).

Pearson correlation coefficient (r) was used to investigate the linear correlation between all pairs of measured parameters in soil and plant (data not shown). All measured growth parameters showed a significant negative correlation (P< 0.01 or 0.05) with leaf K, stem K and P and leaf and stem Zn, Cu and Mn content (with r ranging from -0.41 to -0.91).

Chemical Composition

An ANOVA for the main and combined effects of I and Cd treatments on chemical composition of corn leaf and stem showed that only Fe and Cd concentrations were not affected by I treatments. In addition, cadmium treatments influenced the leaf Cu, Zn and Cd of corn, while I×Cd treatments only affected leaf Mn and stem Zn of the corn plant. Figure 2 shows that corn had significantly more leaf and stem P, stem K, and leaf and stem Zn under water stress conditions, while both plant parts had significantly less amounts of Cu and Mn in the 1-day irrigation interval. Moreover, leaf K significantly increased with increasing irrigation frequencies. According to Figure 3, significant increases in leaf Cu, Zn, and Cd were observed at the highest Cd level. Conflicting findings are reported in the literature regarding the effect of Cd on Zn absorption by plants. For example, Sameni et al. (1987) reported either increase or decrease in Zn concentration of tomato shoot and no significant change in Zn of corn shoot as a result of increasing soil Cd levels. In contrast to our results for Cu, Wallace et al. (1977) indicated that Cd treatment decreased the Cu concentration in corn shoot. Cd-treated plants significantly accumulated more Cd in their leaves than that of the control. The interaction effect of I and Cd treatments on leaf Mn and stem Zn of corn are shown in Table 3. According to Table 3, corn had significantly lower leaf Mn content under optimum soil moisture regime. Furthermore, there was no substantial difference between leaf Mn concentration in the control and Cd-treated plants, a finding which is in agreement with

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Effect of irrigation interval on corn chemical composition: (a) Leaf (L) and stem (S) potassium (K) and phosphorous (P), (b) L and S copper (Cu), zinc (Zn) and manganese (Mn). Means within each plant parameter followed by the same letter are not statistically different at $P \leq 0.05$. 

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Figure 3. Effect of irrigation water Cd levels on corn Leaf Zn, Cu and Cd concentration. Means within each plant parameter followed by the same letter are not statistically different at $P \leq 0.05$.

those of Castillo-Michel et al. (2009) for Mn concentration of corn shoot. Moreover, Zn concentration of corn stems was significantly greater under drought stress conditions.

The Cd concentrations in corn leaf and stem were in the range of 0.9-4.1 and 0.3-4.2 mg kg$^{-1}$ DW, respectively. However, leaves potentially accumulated more Cd than stems by 24, 56, and 27% in 1, 3, and 7-day irrigation intervals, respectively, since they had greater BCFs. Moreover, TF index (Table 5) was generally $>1$ showing that large amounts of Cd were transported to, and accumulated in, the leaves. In the present study, the TF of Cd was to some extent soil moisture dependent and was higher under the 3-day irrigation interval as compared to the other irrigation regimes.

Youn-Joo (2004) reported a TF $<1$ between corn shoot and root indicating that Cd was accumulated mainly in the roots.

Added soil Cd presented a significant positive correlation with leaf Cd and Cu ($P<0.01$) and stem Cd ($P<0.05$). Peralta-Videa et al. (2002) also reported similar correlation in alfalfa plants. In addition, leaf Cd was positively correlated with the Cu ($P<0.05$) and Fe ($P<0.01$) in leaves and the Cd in stems ($P<0.01$; $r=0.54$). A positive correlation was also found between Cd and Fe in the stems. John et al. (1972) also found that concentrations of Cd in plants grown on Cd-treated soils had a significant positive correlation with Fe, Zn, and Cu levels in the same plant part.

### Cd Toxicity

As noted before, it seems that mature leaf tissues were more sensitive to the toxic

<table>
<thead>
<tr>
<th>Irrigation interval (d)</th>
<th>Cd level of irrigation water (mg l$^{-1}$)</th>
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<tbody>
<tr>
<td></td>
<td>Leaf Mn (mg kg$^{-1}$)</td>
</tr>
<tr>
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<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>10.63b $^a$</td>
</tr>
<tr>
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<td>24.37a</td>
</tr>
<tr>
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<td>27.20a</td>
</tr>
<tr>
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<td>1.69cd</td>
</tr>
<tr>
<td>7</td>
<td>13.22a</td>
</tr>
</tbody>
</table>

$^a$ Means within each plant parameter followed by the same letter are not statistically different at $P \leq 0.05$. 

Table 3. Interaction effects of irrigation intervals and Cd levels of irrigation water on leaf Mn and stem Zn of corn.
effects of Cd than stem tissues. Based on the lines of best fit between yield reduction versus Cd concentration, the water and final soil and shoot Cd concentrations required to reduce leaf and stem dry weight by 10 and 50% were calculated (Table 4). According to the results, corn stem was more sensitive to Cd, as certain growth reduction occurred at a lower Cd concentration. In the present study, the corn stem had more complex behavior than the corn leaf as there was no clear significant relationship between its growth reduction and Cd concentration of water, soil and plant. Corn leaf was more tolerant to Cd at the 1 and then the 7-day irrigation interval. Based on the available data, corn stem was also more tolerant to soil and water Cd under water stress conditions. Youn-Joo (2004) observed a median effective concentration value of Cd of corn (the concentration which implies 50% growth reduction, EC$_{50}$) in Cd-amended soils ranging between 208 and 265 mg kg$^{-1}$. In our study, in which corn was gradually exposed to Cd, the results are much lower than those reported by Youn-Joo (2004). Sameni et al. (1987) reported a 50% reduction in the shoot growth of corn occurring at 171 mg Cd kg$^{-1}$ of soil. They also observed that shoot Cd concentration associated with 50% growth suppression was 29 mg kg$^{-1}$ for corn, which was higher than our findings for leaf and stem.

**Potential Use for Phytoremediation**

Research is presently focused on low-cost, easy, and safe technologies for solving environmental problems. Phytoremediation is one of these techniques whereby green plants are used to remove or degrade the environmental pollutants such as heavy metals. In the present study, the Cd-phytoremediation potential of corn was evaluated by $BCF$ (Equation (2)) and the percentage of recovered Cd (Equation (4)). The $BCF$ is an important plant feature in phytoremediation, which implies uptake of pollutants, their mobilization and storage in

<table>
<thead>
<tr>
<th>Growth reduction (%)</th>
<th>Irrigation interval (d)</th>
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<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Leaf</strong></td>
<td></td>
</tr>
<tr>
<td>Irrigation water Cd concentration (mg l$^{-1}$)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>16.00</td>
</tr>
<tr>
<td>50</td>
<td>73.14</td>
</tr>
<tr>
<td>Soil Cd concentration (mg kg$^{-1}$)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>37.67</td>
</tr>
<tr>
<td>50</td>
<td>171.00</td>
</tr>
<tr>
<td>Plant Cd concentration (mg kg$^{-1}$)</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>2.46</td>
</tr>
<tr>
<td>50</td>
<td>9.87</td>
</tr>
<tr>
<td><strong>Stem</strong></td>
<td></td>
</tr>
<tr>
<td>Irrigation water Cd concentration (mg l$^{-1}$)</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>4.42</td>
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<tr>
<td>50</td>
<td>21.08</td>
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<tr>
<td>Soil Cd concentration (mg kg$^{-1}$)</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>6.78</td>
</tr>
<tr>
<td>50</td>
<td>29.00</td>
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<td>Plant Cd concentration (mg kg$^{-1}$)</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>50</td>
<td>-</td>
</tr>
</tbody>
</table>

*a* In these cases there were no clear relationship between growth reduction and Cd concentration.

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the aerial plant parts (Marchiol et al., 2004). The BCF values of >1 indicate that plants have a good ability to take up the contaminants from polluted substrate and accumulate them in their above ground tissue. In this study, The BCF of both plant parts was < 0.5 (Table 5) indicating that corn did not have a satisfactory ability to take up Cd from the soil. Moreover, the leaf BCFs were generally greater, meaning that the potential Cd-accumulation of the leaf was greater than that of the stem. The greatest BCF was obtained at the 7-day irrigation interval (Table 5). The lower BCF under normal soil moisture conditions was mainly due to greater Cd accumulation in the soil as the result of greater amounts of applied water at the 1-day irrigation interval. Robinson et al. (2000) also demonstrated a general decrease in the BCF of forest species with increasing soil Cd levels.

The Cd recovery percentages are shown in Figure 4. At a given Cd level, plants generally recovered more Cd at the 1-day irrigation interval than the other two irrigation regimes. This could be attributed to the higher soil matric potential (Table 5) and, consequently, greater water and metal uptake and higher shoot dry weight. Angle et al. (2003) observed a greater metal uptake and biomass production at higher soil moisture values. The amounts of Cd recovered in this study are not effective in phytoremediation per se. In other words, the recovered Cd was very low even under an optimum soil moisture regime, because of the substantial Cd accumulation in the soil. It seems that most of the Cd applied through irrigation accumulated in the soil and became partially unavailable for plants or concentrated in plant roots. Dikinya and Areola (2010) reported higher soil Cd levels under maize cultivation irrigated with secondary treated waste water relative to the control sites. This may be due to higher adsorption capacity of Cd to clays (Sanchez et al., 1999). From Figure 4, it is also clear that rises in Cd levels decreased the percentage of Cd recovery. It could thus be realistically hypothesized that corn could perform better in the case of light water and consequently soil pollution. In order to artificially enhance Cd uptake, soil amendments might also be used to improve phytoremediation efficiency (Chen and Cutright, 2001; Motesharezadeh et al., 2010).

![Figure 4](https://example.com/figure4.png)

**Figure 4.** Percentage of recovered, uptake (white bar) and added (gray bar) Cd at various irrigation and Cd treatments, (a) 1-day; (b) 3-day, and (c) 7-day irrigation interval.

**Plant Tissue Cd Concentration Model**

Plant uptake of heavy metals is a function of plant species, individual trace elements, and soil characteristics. It may follow many
Table 5. Soil matric potentials, Water Use Efficiency (WUE), leaf and stem Bio concentration Factor (BCF) and Translocation Factor (TF) of corn plant at various irrigation intervals and Cd levels of irrigation water.

<table>
<thead>
<tr>
<th>Irrigation interval (d)</th>
<th>Cd level (mg l(^{-1}))</th>
<th>Soil matric potential (bar)</th>
<th>WUE (g kg(^{-1}) water)</th>
<th>BCF Leaf</th>
<th>BCF Stem</th>
<th>TF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>-0.40</td>
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<td>4.65</td>
<td>0.10</td>
<td>0.13</td>
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<td>4.98</td>
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<td>1.62</td>
<td>0.15</td>
<td>0.17</td>
<td>0.90</td>
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<td>0.17</td>
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<td>20</td>
<td>-2.66</td>
<td>1.32</td>
<td>0.09</td>
<td>0.04</td>
<td>2.33</td>
</tr>
</tbody>
</table>

different rate response functions including linear, asymptotic, no response, or even negative (Page et al., 1987). A hypothesis has been proposed to explain trace element uptake by various crops in which the uptake does not follow a linear trend with trace element application rates, but rather would approach a maximum (plateau) as metal loading increases (Corey et al., 1987). We examined the abovementioned models for Cd concentrations in corn shoot as a function of final soil accumulated Cd concentrations under different irrigation regimes. Grifferty and Barrington (2000) pointed out that plant uptake of trace metal could be different under various transpiration regimes. As Figure 5 shows, the cadmium concentration in corn under each irrigation regime exhibited a plateau-type response that could be modeled with the Mitscherlich plateau equation (Logan and Chaney, 1987) as:

\[ y = a + b(1 - e^{-cx}) \]  

(5)

Where, \( y \) = Shoot metal concentration (mg kg\(^{-1}\)), \( x \) = Soil metal concentration (mg kg\(^{-1}\)), \( a \) = y intercept or background plant tissue concentration (mg kg\(^{-1}\)), \( b \) = Asymptote

Table 6. The results of Equation (5) fitting into the Cd concentration of corn shoot versus accumulated Cd in the soil, at 1-, 3- and 7-day irrigation intervals.

<table>
<thead>
<tr>
<th>Irrigation interval (d)</th>
<th>Coefficients</th>
<th>Coefficient of determination (R(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>1</td>
<td>0.2555 (^a)</td>
<td>2.7214</td>
</tr>
<tr>
<td>3</td>
<td>0.1599</td>
<td>0.8389</td>
</tr>
<tr>
<td>7</td>
<td>0.1369</td>
<td>1.5480</td>
</tr>
</tbody>
</table>

\(^a\) P-value of determination of all coefficients and regression models were <0.001.
CONCLUSIONS

The results of the present study showed that Cd stress induced senescence in corn which was visible on the old leaves. Reduction of growth and water uptake were also observed. However, no substantial nutrient imbalances occurred as a function of Cd application. Cadmium accumulation in leaves was higher than in stems up to a maximum of 56%. Corn leaves were also more tolerant to Cd than stems. Furthermore, shoot Cd concentration followed a plateau-type model with greater potential of Cd accumulation under the 1-day irrigation interval. Although corn plants could recover more added Cd under the 1-day irrigation interval, these amounts do not affirm the potential phytoremediation of maize. Therefore, enhancing the Cd uptake by soil amendments could improve the phytoremediation efficiency. Finally, economical use of cultivated plants for phytoremediation of soils polluted with Cd should be approached with more research and field evaluation.

REFERENCES


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واکنش درت به تنش کادمیم و خشکی و پاتنسل استفاده از آن برای گیاه بالایی

ا. عزیزیان، س. امین، م. مفتون، ی. امام و م. نوشادی

چکیده

در این پژوهش اثر سطوح مختلف کادمیم آب آبیاری (صفر، 5، 10 و 20 میلی گرم در لیتر) بر گیاه ذرت (شاخسار) تحت سطح مختلف آبیاری (1، 3 و 7 روز) بررسی شد. نتایج نشان داد که وسعت خشکی و بدنان آلی تغذیه و ارتفاع گیاه حساس ترین پارامترهای ویژگی‌های گیاهی به انرژی سطوح کادمیم آب آبیاری بودند. باعث شده کادمیم سپر کاهش جذب آب و طول عمر نشان دهند در خاک گردید. نتایج همچنین این مطالعه بود که ذرت در شرایط ووجود کادمیم ممکن است به توجه به تولید کند که با وجود نبود آثار ظاهری سمت کادمیم همراه با مقادیر قابل توجه جذب این عناصر، با اینکه مورد توجه قرار گیرد. کاربرد کادمیم در آب آبیاری احتمالاً می‌تواند در بازیابی گیاهی ایجاد نکند. تماشای به تجربه کادمیم در برگ بیش از سطح و به ترتیب 24، 65، 7 و 42 درصد در دوره‌های 1، 3 و 7 روز بوده. همچنین سطح ذرت نسبت به کادمیم حساسیت بیشتری در برگ بود. نتایج نشان داد که ذرت ممکن است در شرایط رطوبت بالای حالت و آلوگی خفیف با کادمیم برای گیاه بالایی استفاده شود. همچنین غلظت کادمیم شاخسار ذرت در plateau مقایل غلظت کادمیم خاک در هر دور آبیاری با مدلی از نوع پیان گردید.