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Modeling Phytoremediation of Cadmium Contaminated Soil with Sunflower (*Helianthus annus*) Under Salinity Stress

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ABSTRACT: This study was carried out as a factorial experiment with 5 levels of cadmium (Cd) (o, 25, 50, 75, and 100 mg/kg), 5 levels of salinity (Control, 4, 5, 6, and 7 dS/m), and two soil textures (sandy loam and clay loam). The results showed that the amount of Cd in root and shoot of sunflower increased as soil salinity and Cd concentration increased. The best concentrations for Cd phytoremediation were 75 mg/kg in sandy loam and 100 mg/kg in clay loam. Mass-Hoffman model in simulating transpiration Cd stress as well as Homaee model in simulating salt stress indicated the best results in light soils. By multiplying the salinity stress model by Cd stress model, the simultaneous model for each soil was calculated. These models in light soil (r^2=0.68) and heavy soil (r^2=0.81) were compatible with measured values. In the heavy soil, absorbed Cd by plant along with increased salinity reflected low changes, but changes in Cd absorbed by plants in the heavy soil were more uniform than in the light soil. In conclusion, for estimating the Cd uptake, the model had a better performance in the heavy soil (under salt stress).

Key words: Cadmium, Modeling, Phytoremediation, Salinity, Sunflower

INTRODUCTION

Soil as a non-renewable natural resource is being damaged by adding various pollutants including heavy metals. Eventually, this damage leads to decreased crop yield and quality (Henry, 2000). There are several physical, chemical, and biological methods to remove heavy metals from contaminated soils. However, physical and chemical methods are costly and yet pose harmful effects to physical, chemical, and biological soil characteristics. Phytoremediation is the use of green plants for the remediation of contaminated sites. This is a relatively feasible, environmentally friendly, and promising approach for effective removal of pollutants from the soil environment (Mccutcheon and Jorgensen, 2008).

Soil salinization affects 1-10 billion ha worldwide, threatening the agricultural production needed to feed the ever increasing world population (Jesus *et al*., 2015). Additionally, a wide range of existing areas throughout the world has been covered with saline soils, which are mainly abandoned because of salt restriction. Theses lands will eventually become wastelands or local garbage dumps. The effects of high salt concentrations in soils are marked in plants, which exhibit physiological charges including stomata closure, hyper osmotic shock, inhibition of cell division, and photosynthesis. However, the most common effects are nutrient imbalance, low osmotic potential, and toxicity of specific ions such as Na^+ and Cl^-, resulting in plant growth inhibition or even death (Aslam *et al*., 2011). The salinity can cause to increase Cd concentration in soil solution and hence its uptake by plants; this can come from increased bioavailability of Cd because Cd salt cation displacements in the clay, and also, increased mobility of Cd ions by the available anions at salt, which is of course dependent on the type of salt and soil type (Mc Laughlin, 1999). It seems that further supplying of Cd in the soil in the presence of chloride salinity coming from chloride existence inhibits Cd absorption to the clay surface, and is moving in the soil solution in $CdCl_2$ form (Stevens, 2003). The researchers

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conclude that the salinity will lead to serious consequences of Cd accumulation intensification in the Glycophytic plants such as potatoes, sunflower and maize (Mc Laughlin, 1994; Helal, 1996).

Modeling of mineral or pollutant absorption by plant roots follows two methods: microscopic and macroscopic approach, in which macroscopic models are more important for reporting the results of the process. Oyang (2002) investigated the feasibility of green extraction of Zn and Cd by *Thalaspi carlensens*. They established regression models for estimating metal concentration in the shoots and metal bioaccumulation factor based on total metal concentration in the soil. They concluded that the amount of green extraction is connected to the crop yield, bioaccumulation factor, and the amount of soil, which should be refined. Sepaskhah and Yousofi-falakdehi (2010) applied macroscopic root water uptake equation for modeling rice yield in salinity and water stress. They showed that FAO method was not able to estimate interactions between water and salinity stresses in reduction of water absorption, particularly in high levels of soil salinity. They found that the model obtained by Homaee *et al.* (2002) could well determine simultaneous interactions of water and salinity stresses on water absorption coefficient of the root. Khodaverdiloo and Homaee (2008) investigated phytoremediation of soils contaminated by Pb and Cd using a deterministic model in which they integrate the reduction functions with soil metal sorption isotherm parameters. They reported that with increasing concentration of Pb in the soil, spinach and land cress did a better soil phytoremediation. However, with increasing Cd level, the ability of spinach and land cress for soil phytoremediation did not change. Ultimately, with the combination of soil isothermal reaction and plant reaction in extracting pollutants, models with a high performance ($r^2 > 0.98$) were obtained for estimating the time needed to remove Pb from the soil. By applying this model, researchers reported that in Ni+Cd treatments, growth and development of plants were more affected than in either Ni or Cd treatments. At constant Ni concentration, adding Cd did not appreciably changed Ni content of plant tissues (Davari *et al*., 2015). The model predicts that phytoremediation process takes much longer time when soil is contaminated by multiple metal ions.

This study is aimed at 1) modeling Cd uptake estimation in sunflower using transpiration models in different levels of salinity and soil Cd; and 2) predicting phytoremediation potential.

MATERIALS & METHODS

In the current study, the amount of Cd phytoremediation was studied in two different soil texture classes: a relatively light and a heavy texture. The heavy textured soil was collected from the research center for University College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran. For producing the other texture (relatively light), some sand was added to the soil, then, all soil samples were passed through a 4 mm sieve. Some of either soil was passed through a 2 mm sieve after air drying. After that, major physical/chemical properties of the soils were measured by standard methods (Table 1) (Sparks *et al*., 1996). The soils were contaminated by Cd using $Cd(NO_3)_2$ at five concentrations (0, 5, 25, 50, 75, and 100 mg/kg) by spraying the solution on all parts of the soils. The pots were kept in incubation conditions for 6 months for achieving equilibrium and obtaining more normal contamination conditions. This time period depends on soil texture and contamination type; in fact, more heavier soil texture, more required time for achieving balance between soil and pollution (Mc Laughlin, 1999; Yizang and Yunxia, 2009). The main reasons for applying $Cd(NO_3)_2$ in this study was its low salinity coefficient (compared to $CaCl_2$) and its good solubility in water. In addition, its anion (nitrate) is nutritious for the plant. The amount of nitrate added to the soils was calculated and subtracted from the amount of urea fertilizer consumed during the growth period. Planting sunflower seed, exercising salinity stresses, and vegetation period. After 6 months of incubation period, the pots were transferred to the greenhouse of Soil Science Department, University of Tehran. After that, in each 3.5-kg-pot, 4 sunflower seeds (Progress variety) were cultivated. Subsequently, after the 4-leaf stage, they were thinned to two plants. After germination, the soil in each pot was salinized by dissolving equal amounts of salts (including NaCl and $CaCl_2$ at 5 levels of salinity with different capabilities of electrical conductivity including control, 4, 5, 6, and 7 dS/m by means of TDS = 640×EC formula in the distilled water. The pots were irrigated during vegetation period using distilled water in order to maintain soil moisture at field capacity level. In order to minimize soil evaporation, all pot surfaces were equally covered with sand so that nearly all consumed water in the pots to be used for plant transpiration. Before watering, all pots were weighed and the values were recorded so as to apply in plant transpiration models. Thus, the amount of water used by plants was recorded. Plants after 70 days of germination, and at the end of the vegetative growth period, were harvested, and some physiological characteristics of the plant were measured, and the amount of their Cd was registered using an atomic absorption spectrophotometer, Shimadzu Model 670, and the uptake values were calculated with respect to the produced dry matter weight (Emami, 1996). In this study, the obtained data were fitted in different models such as Maas-Hoffman and Homaee models, and the models parameters were estimated by optimization of least sum of square errors method. The ability of applied models were utilized by root mean square error (RMSE), efficiency of model (EF), coefficient of residual mass (CRM), maximum error (ME), and coefficient of determination (CD), and finally the best model were chosen. These indices are calculated as follows:

$$RMSE = \left[\frac{\sum_{i=1}^{n}(predicted_i - Observed_i)^2}{n}\right]^{0.5} \quad (1)$$

$$EF = \frac{\sum_{i=1}^{n}(Observed_i - \overline{Observed})^2 - \sum_{i=1}^{n}(predicted_i - Observed_i)^2}{\sum_{i=1}^{n}(Observed_i - \overline{Observed})^2} \quad (2)$$

$$CRM = \frac{\sum_{i=1}^{n} observed_i - \sum_{i=1}^{n} predicted_i}{\sum_{i=1}^{n} observed_i} \quad (3)$$

$$ME = MAX|predicted_i - Observed_i| \quad (4)$$

$$CD = \frac{\sum_{i=1}^{n}(Observed_i - Observed)^2}{\sum_{i=1}^{n}(predicted_i - Observed_i)^2} \quad (5)$$

where $Observed_i$ and $predict_i$ are measured and estimated value, respectively. The best model is one in which RMSE, ME, and CRM indices are closer to zero, in addition, CD and EF indices are closer to one. After selecting the best transpiration model, the amount of absorbed Cd under salinity conditions was modeled by following equation:

$$r_0 = T_a . \beta . C_l \quad (6)$$

where r_0 is phytoremediation of Cd from the soil under saline conditions (mg/m^2), T_a is plant transpiration rate (l/m^2), C_l is pollutant concentration in the soil solution phase (mg/L), and β is factor of pollutant concentration in the transpiration stream, which is dependent on soil, plant and pollutant type, (Khodaverdiloo and Homaee, 2008). In this study, two treatments of salinity and Cd were applied at five salinity levels and five Cd levels in three replicates and two different soil texture classes. In the present study, wet and dry weights of shoot and root, Cd concentration in shoot and root, absorbed Cd in each plant, and zinc concentration in shoots of sunflower plants were measured. In statistical analyses, factorial design was employed in CRD format design using SPSS software. Moreover, plotting the graphs was done in Microsoft Excel software, and OriginPro software was used for estimation of models parameters. In order to comparison of the means, LSD method was used at 5% level.

RESULTS & DISCUSSION

The results of physical and chemical analyses of two studied soils (Sandy Loam and Clay Loam): In the following table, the results of physical and chemical analyses of two types of soils including light and heavy have been presented (Table 1). As it can be seen in Table 1, the amount of Cd in these two soils is low, and there is almost no difference between them in such a way that this matter minimize the error caused by Cd differences in two studied soils. pH values of two soils are the same and electrical conductivity of two soils doesn't differ as well. Moreover, in terms of nutrients, in both soils based on soil analysis test results, fertilizer recommendation was applied.

Selecting the best transpiration model of sunflower under salinity and cadmium stresses in two soil texture classes (sandy loam and clay loam): Sunflower relative transpiration

As expected, along with an increase in Cd and salinity stress, transpiration of plant decreased. Figure 1 illustrates sunflower transpiration trend with increasing

Table 1. Analysis of physical and chemical characteristics of soils

Characteristic	Value (Clay Loam Texture)	Value (Sandy Loam Texture)	Characteristic	Value (Clay Loam Texture)	Value (Sandy Loam Texture)
Clay (%)	28	18	P (mg/kg)	9.3	2
Silt (%)	35	20	K (mg/kg)	95	121
Soil Texture Class	CL	SL	Fe* (mg/kg)	7.32	6.35
pH	8.4	8.4	Cu* (mg/kg)	1.62	1.15
EC (dS/m)	1.13	1.43	Mn* (mg/kg)	19.6	15.4
Total N (%)	0.069	0.035	Zn* (mg/kg)	1.11	0.96
CCE (%)	7.1	4.35	Cd* (mg/kg)	0.13	0.11
OC (%)	0.62	0.38	CEC ($cmol_c$/kg)	23.6	14.73

*DTPA extractable

salinity and Cd concentration in two soils of light and heavy textures. According to this figure, the highest amount of transpiration in both soils was observed in control treatment (C_0S_1). Decreasing of plant transpiration in light textured soil with increase in salinity at the same levels of Cd in soil, reflected less slope than heavy textured soil, so this point is likely due to less clay and CEC of light textured soil (sandy loam) , also it can be derived from this point that dissolved salts move away from near root distances more than heavy textured soils (clay loam) which can be why by increasing salinity the amount of absorbed soil Cd in light textured soils changes less than heavy textured soil. In control treatment, furthermore, along with increase of Cd concentration in the soil, plant transpiration reduction in light texture soil, is more than the heavy texture soils. In light textured soil owing to less clay as well as CEC mounts, less Cd amount can be stabilized than heavy textured soil, and therefore, the amount of Cd that can be absorbed in light textured soil is more than light textured soil; consequently, it leads to more stress in the plant. As a result, plant transpiration value is decreased further.

In order to select the best transpiration model, at first step, constant coefficients of Maas-Hoffman (1977), Van Genechten-Hoffman (1984), Dirksen *et al* (1993), and Homaee *et al* (2002) models once in salinity stress conditions, and once again under Cd stress conditions were obtained in two soils of light and heavy texture (sandy loam and clay loam) using sum of squared errors optimization method. In Tables 2 and 3, models parameters in the salinity and Cd stresses, respectively in the soils with light and heavy texture (sandy loam and clay loam) have been presented. In these tables, constant value of $\left(\frac{1-\alpha_0}{\alpha_0}\right)$ in Homaee model (2002) is considered equal to k.

After estimating transpiration models parameters in Cd and salinity stresses in two soils, CRM value is applied as an index for investigating underestimation or overestimation than actual value. When CRM is negative, it means an overestimation than real amount. The EF value compares estimated values with average measured values, and its negative amount demonstrates that the average measured values model estimations better than estimated values. The CD amount shows the ratio of the estimated values distribution to measured values. The ME value indicates the inadequacy of the model, so the greater ME, the more inefficient model. The RMSE value shows that estimated values by the model are higher or lower than actual amounts. As mentioned before, the most acceptable model is one in which indices including RMSE, ME, and CRM are closer to zero, and on the other side, CD and EF indices are closer to one. According to aforementioned points as well as Table 4, Maas-Hoffman model in modeling plant transpiration under Cd stress, and Homaee model in modeling plant transpiration under salinity stress in the soil with light texture (sandy loam) had the best performance. Furthermore, according to Table 5, Homaee model in modeling plant transpiration under Cd stress and Maas-Hoffman model in modeling plant transpiration under salinity stress in the soil with heavy texture showed the best efficiency.

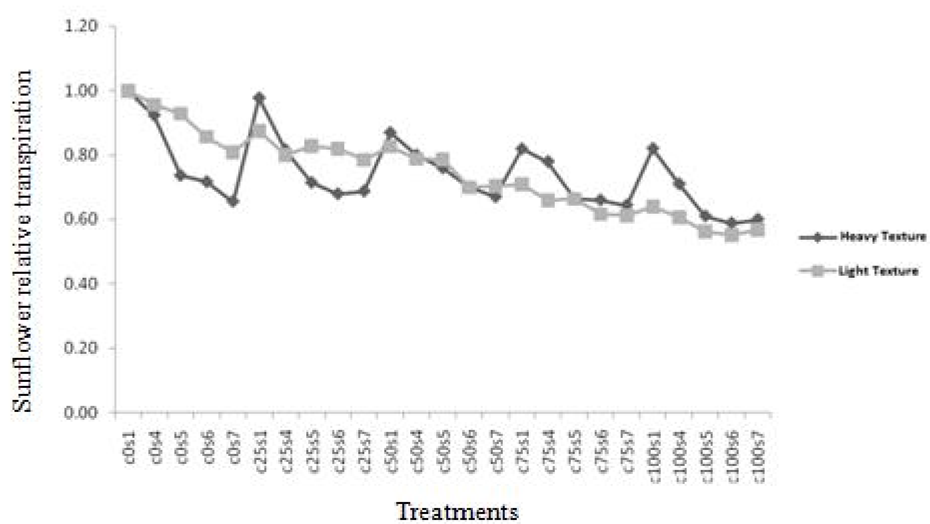

Fig. 1. Relative transpiration of sunflower plant in different treatments concerning two soils of light and heavy texture (sandy loam and clay loam). (C_0: cadmium 0 mg/kg, C_{25}: cadmium 25 mg/kg, C_{50}: cadmium 50 mg/kg, C_{75}: cadmium 75 mg/kg and C_{100}: cadmium 100 mg/kg, S_1: EC in control treatment dS/m, S_4: EC 4 dS/m, S_5: EC 5 dS/m, S_6: EC 6 dS/m and S_7: EC 7 dS/m)

Table 2. Optimized parameters of sunflower transpiration models in sandy loam texture soil

Model	Parameter	Optimal parameter (for cadmium)	Optimal parameter (for salinity)
Maas-Hoffman	α	0.00355	$3.20E^{10^{\wedge}0.1}$
	h_0*,C_s*	-3.4954	65.82659
Van-Genuchten	P	-0.01871	-13.77854
	$h_{050},C_{s\,50}$	$-1.11E^{-33}$	5.33886
Dirksen	h_0*,C_s*	$3.19E^{+0.8}$	$6.25E^{+0.7}$
	h_{050},C_s50	-1.19+0.9	$-2.10E^{+0.8}$
	P	0.93185	1.57308
Homaee	h_0*,C_s*	-2.47616	40.55286
	$h_{050},C_{s\,50}$	18.31391	123.9866
	k	0.08299	0.02498
	P	1.18933	2.44076

Table 3. Optimized parameters of sunflower transpiration models in clay loam texture

Model	Parameter	Optimal parameter (for cadmium)	Optimal parameter (for salinity)
Maas-Hoffman	α	0.00261	-0.58526
	h0*,Cs*	0.75367	33.46732
Van-Genuchten	P	-0.02481	-0.01655
	h050,Cs 50	$1.22E^{-33}$	$1.19E^{-32}$
Dirksen	h0*,Cs*	$2.93E^{+0.7}$	-116.68194
	h050,Cs50	-1.02+0.8	-116.68115
	P	1.27893	-0.10198
Homaee	h0*,Cs*	0.11949	$-1.83E^{+0.6}$
	h050,Cs 50	22.06259	-3613.69607
	k	0.0631	0.73636
	P	1.11015	-18726.61101

Table 4. The results of evaluating transpiration models in sandy loam texture soil

Stress	Model	RMSE	EF	CRM	CD	ME
Cadmium	Maas-Hoffman	0.015626	-0.22242	0.0001687	0.81805	0.0238413
	Van-Genuchten	0.132532	0.784664	-0.003825	0.017167	-0.20099
	Dirksen	0.126271	0.764701	$6.3427E^{-6}$	4.249912	-0.18986
	Homaee	0.015952	-0.2098	0.0003209	0.826586	-0.02654
Salinity	Maas-Hoffman	0.023894	-0.615457	$-3.2109E^{-7}$	0.028414	-0.0302
	Van-Genuchten	0.113009	-0.11928	-0.098469	0.893433	-0.191071
	Dirksen	0.068813	0.897409	$3.40863E^{-6}$	9.747402	0.1013977
	Homaee	0.001608	0.580424	$7.3490E^{-5}$	0.0310027	0.0099505

Table 5. The results of evaluating transpiration models in the heavy textured soil (Clay Loam)

Stress	Model	RMSE	EF	CRM	CD	ME
Cadmium	Maas-Hoffman	0.033664	0.1178459	$-1.7844E^{-5}$	1.1335888	0.060355
	Van-Genuchten	0.103709	0.9934115	-0.004409	151.77693	0.1385072
	Dirksen	0.098154	0.9999999	$5.2853E^{-5}$	4541944	-0.128657
	Homaee	0.031954	0.1558958	0.0026259	1.1846878	0.0531807
Salinity	Maas-Hoffman	0.01549	0.0169850	$-7.9520E^{-7}$	1.0172784	0.025667
	Van-Genuchten	0.120687	0.997376	-0.000756	3811.9495	-0.219252
	Dirksen	0.124021	0.9977962	0.002758	453.76640	-0.223677
	Homaee	0.246843	-2.311803	-0.276052	0.3019503	0.344444

To determine transpiration value under simultaneous salinity and Cd stresses, selected models were multiplied by each other under salinity and Cd stress. Equations number 7 and 8 display optimal models under simultaneous salinity and Cd stresses in the soil with light texture and heavy texture, respectively. Besides, Figs 2 and 3 illustrate the comparison between estimated transpiration values obtained from the model with actual measured amounts, respectively in the soil with light and heavy textures. These mentioned figures demonstrate that chosen models in the soils with light and heavy textures are appropriately able to determine plant transpiration amount.

$$\mathbf{T_a} = \frac{\mathbf{T_m}}{1+(0.02498)\left(\frac{40.55286-h_0}{-83.43374}\right)^{2.44076}} \cdot (1-(0.00355)(c_{cd}-3.4954)) \tag{7}$$

$$T_a = \frac{T_m}{1+(0.0631)\left(\frac{0.11949-c_{cd}}{-21.9431}\right)^{1.11015}} \cdot (1-(-0.0016257)(33.46732-h_0)) \tag{8}$$

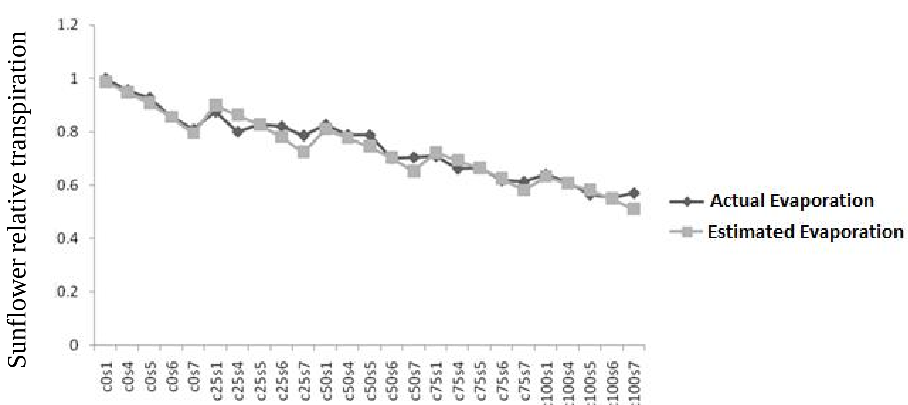

Fig. 2. The comparison between estimated plant transpiration by model with actual transpiration in light textured soil (sandy loam). (C_0: cadmium 0 mg/kg, C_{25}: cadmium 25 mg/kg, C_{50}: cadmium 50 mg/kg, C_{75}: cadmium 75 mg/kg and C_{100}: cadmium 100 mg/kg, S_1: EC in control treatment dS/m, S_4: EC 4 dS/m, S_5: EC 5 dS/m, S_6: EC 6 dS/m and S_7: EC 7 dS/m)

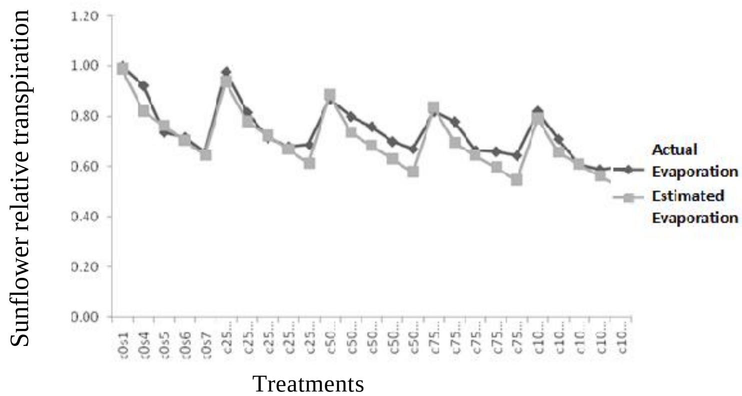

Fig. 3. The comparison between estimated plant transpiration by model with actual transpiration in heavy textured soil (Clay Loam). (C_0: cadmium 0 mg/kg, C_{25}: cadmium 25 mg/kg, C_{50}: cadmium 50 mg/kg, C_{75}: cadmium 75 mg/kg and C_{100}: cadmium 100 mg/kg, S_1: EC in control treatment dS/m, S_4: EC 4 dS/m, S_5: EC 5 dS/m, S_6: EC 6 dS/m and S_7: EC 7 dS/m)

Cadmium uptake modeling under saline conditions in two soils with different textures (sandy loam and clay loam): The amount of absorbed Cd from the soil or rate of Cd phytoremediation from the soil in plant is achieved by following equation:

$$r_0 = T_a . \beta . C_l \qquad (9)$$

where r_0 is phytoremediation of Cd from the soil under saline conditions (mg/m^2), T_a is plant transpiration rate (l/m^2), C_l is pollutant concentration in the soil solution phase (mg/L), and β is factor of pollutant concentration in the transpiration stream, that is a proportion of dissolved Cd which is entered into the root system through transpiration stream, and is dependent on pollutant type, soil, and plant. Additionally, C_l is calculated from Equation 10 in which C_s is total concentration of pollutant in the soil (mg/kg), ρ_b is soil bulk density (kg/m^3), θ_v is soil volumetric moisture , and ε is solubility factor of Cd in the soil (Khodaverdiloo and Homaee, 2008).

$$C_l = \varepsilon \frac{c_s \rho_b}{\theta_v} \qquad (10)$$

With modeling transpiration amount in the soils with heavy and light textures, putting the modeled values to the equation 9, and also replacing equation 10 into 9, the equation number 9 will be altered to the following format. Equation 11 shows uptake model of Cd in light textured model, and equation 12 shows uptake model of Cd in heavy textured model.

where ∂ is obtained from multiplying β by ε, and this parameter depends on the plant, soil, pollutant type. Value of this parameter has been presented in Table 6 for two soils of light and heavy texture. Figs 4 and 5 show absorbed Cd amount in the soil with light and heavy texture. As it is obviously comprehensible, based on figures 4 and 5, obtained models for light textured soil (with r^2=0.68) and heavy textured soil (with r^2=0.81) are properly compatible with measured data. Estimated data by means of the model, under low stresses reflected appropriate compatibility with measured data, while under high salinity and Cd stresses it had lower accuracy, and estimated value was more than actual one. That can be because of different plant behavior under the conditions of high salinity and Cd stresses. Under high salinity conditions and high Cd stresses, although concentration of Cd is high, the amount of Cd in the plant is decreased owing to plant weight reduction. Absorbed Cd by the plant had more uniform changes with increasing salinity amount in heavy textured soil than light textured soil; for this reason, the model revealed a higher performance for predicting Cd uptake in heavy textured soil under salinity stress. Equations 13 and 14 display final model of Cd uptake, respectively in the soils with light and heavy textures.

$$r_0 = \partial \frac{c_s \rho_b}{\theta_v} \frac{T_m}{1+(0.02498)\left(\frac{40.55286-h_0}{-83.43374}\right)^{2.44076}} . (1-(0.00355)(c_{cd}-3.4954) \qquad (11)$$

$$r_0 = \partial \frac{c_s \rho_b}{\theta_v} \frac{T_m}{1+(0.0631)\left(\frac{0.11949-c_{cd}}{-21.9431}\right)^{1.11015}} . (1-(-0.0016257)(33.46732-h_0)) \qquad (12)$$

$$r_0 = 0.00018711 \frac{c_s \rho_b}{\theta_v} \frac{T_m}{1+(0.02498)\left(\frac{40.55286-h_0}{-83.43374}\right)^{2.44076}} . (1-(0.00355)(c_{cd}-3.4954)) \qquad (13)$$

$$r_0 = 0/00015222 \frac{c_s \rho_b}{\theta_v} \frac{T_m}{1+(0.0631)\left(\frac{0.11949-c_{cd}}{-21.9431}\right)^{1.11015}} . (1-(-0.0016257)(33.46732-h_0)) \qquad (14)$$

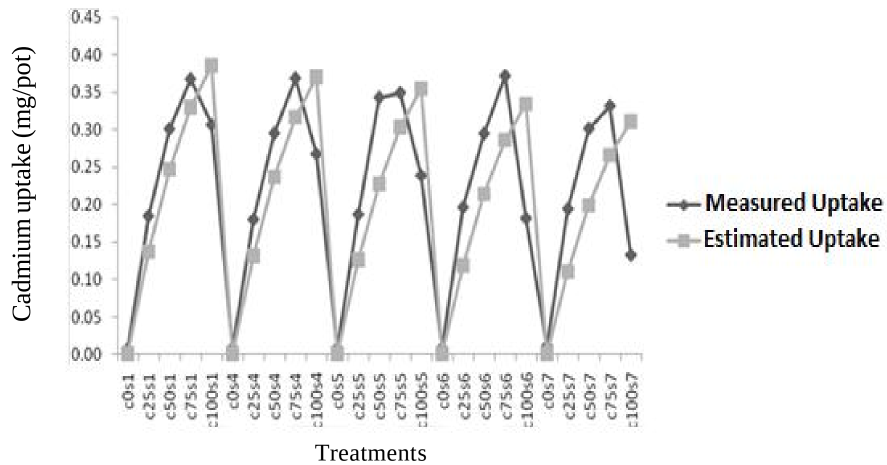

Fig. 4. The comparison of estimated cadmium amount of plant by the model with measured cadmium amount of plant in the light textured soil.

(C_0: cadmium 0 mg/kg, C_{25}: cadmium 25 mg/kg, C_{50}: cadmium 50 mg/kg, C_{75}: cadmium 75 mg/kg and C_{100}: cadmium 100 mg/kg, S_1: EC in control treatment dS/m, S_4: EC 4 dS/m, S_5: EC 5 dS/m, S_6: EC 6 dS/m and S_7: EC 7 dS/m)

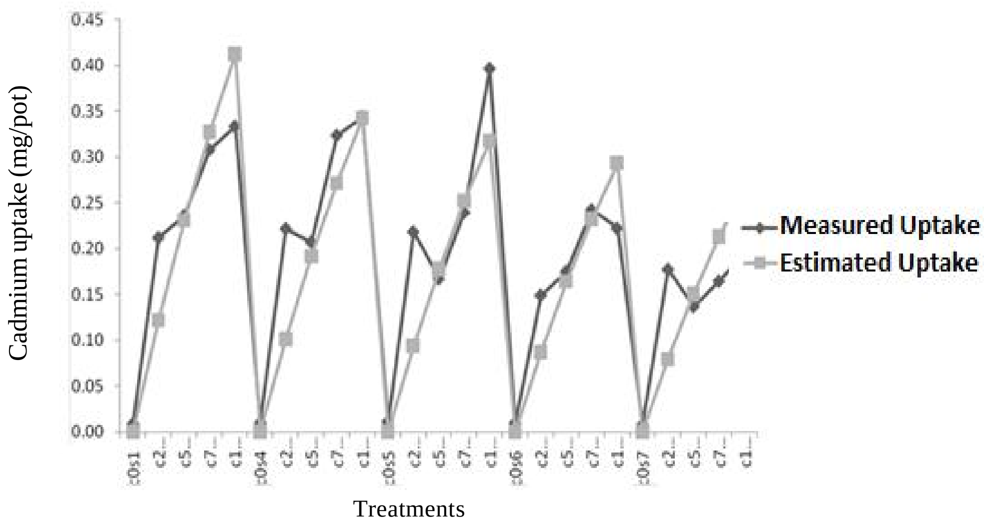

Fig. 5. The comparison of estimated cadmium amount of plant by the model with measured cadmium amount of plant in the heavy textured soil

(C_0: cadmium 0 mg/kg, C_{25}: cadmium 25 mg/kg, C_{50}: cadmium 50 mg/kg, C_{75}: cadmium 75 mg/kg and C_{100}: cadmium 100 mg/kg, S_1: EC in control treatment dS/m, S_4: EC 4 dS/m, S_5: EC 5 dS/m, S_6: EC 6 dS/m and S_7: EC 7 dS/m)

Table 6. Optimal parameter of cadmium uptake model in two textures (clay loam and sandy loam)

Soil Texture	Parameter	Optimal amount of parameter
clay loam (Heavy)	∂	0.000152224
sandy loam (light)	∂	0.000187117

To confirm the obtained results of current study, and the inverse effects of Cd on the growth plant, the results of Shafi *et al* (2010) can be pointed out. These scholars reported that Cd stress and NaCl salt lead to weight reduction of root and shoot, and in general, decrease the number of lateral roots, total length of roots, the average of root diameter, and whole root volume. Furthermore, the mentioned conditions contribute to change roots to woody form. It seems that further supplying of Cd in the soil in presence of chloride salinity comes from the fact that existing chloride prevents absorption of Cd to the clay surface, and moves in the soil solution as $CaCl_2$ form. Stevens (2003) in addition to Sepaskhah and Yousofi-falakdehi (2010) in rice yield modeling under water deficiency stress utilized macroscopic function of root uptake. The results showed that FAO approach was not able to determine in decreasing water uptake under an interaction between both salinity and water deficiency stresses, especially under high salinities. However, Homaee-Feddes model could reflect simultaneous impacts of two stresses including salinity and water deficiency on the rot water absorption. Additionally, rice yield was also estimated by uptake water function of FAO and Homaee-Feddes. Since the best estimation of recorded data is merely achieved from the linear function, high value of r^2 in the models and its close amounts to one indicates high performance of the model. According to the mentioned facts, the results of present study were compatible with Khodaverdiloo and Homaee (2008) and Tudoreanu and Phillips (2004). Khodaverdiloo and Homaee (2008) in their study reported that the fitted models showed a high performance (r^2=0.98) in estimating lead phytoremediation of soil, and concerning Cd this performance was reported more than 0.70 (r^2=0.70). With respect to the results of the current study, obtained models of uptake in light textured soil with r^2=0. 68 and heavy textured soil with r^2=0.81 had compatibility with the actual recorded data.

CONCLUSIONS

The average amount of Cd uptake through the plant in 5 levels of salinity increased along with Cd concentration increase in both textures of light and heavy (sandy loam and clay loam). It should be considered that in light textured soil (sandy loam) in the concentration 100 mg/kg, average Cd uptake decrease; this uptake reduction is due to weight reduction of sunflower in the concentration level of 100 mg/kg; although Cd concentration was high, Cd uptake by the plant decreased. Therefore, among concentrations including control, 25, 50, 75, and 100 mg/kg, the best concentration of Cd in the soil in order to phytoremediation in light texture was 75 mg/kg and in heavy texture, 100 mg/kg. When the soil salinity increases, the average Cd uptake by the plant in all levels of Cd, owing to decrease of plant biomass will decrease. In salinities including control, 4, and 5 dS/m, Cd uptake decline with a lower slope, while in 6 and 7 dS/m of salinity the mentioned reduction slope is greater. In general, the best soil salinity for Cd phytoremediation by sunflower was less than 5 dS/m in light and heavy soils. Maas-Hoffman model in determining plant transpiration under Cd stress, and Hoffman model in determining plant transpiration under salinity stress in light textured soil (sandy loam) showed the best performance. Besides, Homaee model in modeling plant transpiration under Cd stress, and Maas-Hoffman in modeling plant transpiration under salinity stress in heavy textured soil (clay loam) reflected the best performance. Multiplying Cd and salinity stresses, plant transpiration for simultaneous stresses in each soil is gained. The obtained uptake models in the light textured soil (sandy loam) (r^2=0.68) and heavy textured soil (clay loam) (r^2=0.81) are compatible with actual measured data. Estimated data using model, in lower salinities showed an appropriate compatibility with actual observed data. Overestimation and underestimation of model over measured data is seen because the plant has different behavior in high levels of salinity in absorbing Cd. In high salinity treatments and high Cd amounts, although Cd concentration in the plant is high, Cd amount of plant was reduced, due to reduction of plant weight. Absorbed Cd by the plant had more uniform changes in the soil with heavy texture (clay loam) than light texture (sandy loam). Due to this reason, the model had more efficiency for predicting Cd uptake in heavy textured soil (clay loam) under salinity stress.

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REFERENCES

Aslam, R. Bostan, N. Nabgha-e, A. Maria, M. and Safdar, W. (2011). A critical review on halophytes: salt tolerant plants, Journal of Medicinal Plants Research. **5,** 7108-7118.

Davari, M. Homaee, M. and Rahnemaie, R. (2015). An analytical deterministic model for simultaneous phytoremediation of Ni and Cd from contaminated soils, Environmental Science and Pollution Research, **22,** 4609-4620.

Dirksen, C., Koorevaar, K.B., VanGenuchten, M. Th. (1993). HYSWASOR-Simulation model of hysteretic water and solute transport in the root zone. Page: 99-122. In: Russo, D. and G. Dagan (Eds.), Water Flow and Solute Transport in Soils Springer Verlag, New York.

Emami, A. 1996. Methods of plant analysis. Technical bulletin, No. 982. Soil and Water Research Institute, Karaj, Iran.

Helal, M.H., Upenov, A. and Issa, G.J. (1999). Growth and uptake of Cd and Zn by *Leucaena leucophala* in reclaimed soils as affected by NaCl salinity, Journal of Plant Nutrition and Soil Science. **162,** 589-592.

Henry J. R. (2000). In An Overview of Phytoremediation of Lead and Mercury. NNEMS Report, Washington DC, 3-9.

Homaee, M. Dirksen, C. and Feddes, R. (2002). Simulation of root water uptake. III. Nonuniform transient combined salinity and water stress. Agricultural Water Management. **57(2),** 127-144.

Jesus, J. M., Danko, A. S., Fiuza, A. and Borges, M.T. (2015). Phytoremediation of salt-affected soils: a review of processes, applicability, and the impact of climate change, Environmental Science and Pollution Research. **22,** 6511-6525.

Khodaverdiloo, H. and M. Homaee. (2008). Modeling of Cadmium and Lead Phytoextraction from Contaminated Soils. Polish Journal of Soil Science. **41 (2),** 149-162.

Maas, E.V. and Hoffman, G. J. (1977). Crop salt tolerance current assessment. Journal of Irrigation and Drainage Engineering. **103,** 115-134.

Mccutcheon, S. C. and Jorgensen, S. E. (2008). Phytoremediation. Chapter 2, Encyclopedia of Ecology. Elsevier Science BV, Amsterdam, Netherlands, 2751-2766.

McLaughlin, MJ, Parker, DR., and Clarke, JM. (1999). Metals and micronutrients-food safety issues. Field Crops Research. **60(1-2),** 143–163.

McLaughlin, M.J., Tiller, K., Naidu, R., and Smolders, E. (1994). Review of impurities in fertilizers in Australia prepared for the Fertilizer Industry Federation of Australia [restricted]. Consultancy Report. Division of Soils. CSIRO Australia, 134p.

Ouyang, Y. (2002). Phytoremediation: modeling plant uptake and contaminant transport in the soilplantatmosphere continuum. Journal of Hydrology, 266, 66-82.

Sepaskhah, A.R. and Yousefi-Falakdehi, A. (2010). Rice Yield Modeling under Salinity and Water Stress Conditions using an Appropriate Macroscopic Root Water Uptake Equation, Pakistan Journal of Biological Sciences, **13(22),** 1099-1105.

Shafi, M., GuoPing, Z., Bakht, J., Khan, M.A., Ul-islam, E., and Raziuddin, M.D. (2010). Effect of cadmium and salinity stresses on root morphology of wheat, Pakistan Journal of Botany, **42(4),** 2747-2754.

Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N.,Johnston, G.T. and Sumner, M.E. (1996). Methods of soil analysis, Soil Sci. Soc. Amer., Madison, Wisconsin, USA.

Stevens, D.P., McLaughlin, M.J. and Heinrich, T. (2003). Determining toxicity of lead and zinc runoff in soils: salinity effects on metal partitioning and on phytotoxicity, Environmental Toxicology and Chemistry, **22,** 3017-3024.

Tudoreanu L. and Phillips, C.J.C. (2004). Empirical models for Cadmium accumulation in maize, ryegrass and soybean plants. Journal of the Science of Food and Agriculture, **84,** 845-852.

Van Genuchten, M. Th. and Hoffman, G.j. (1984). Analysis of crop salt tolerance data. Page: 258-271. In I. Shainberg and J. Shalhevet (Eds.), Soil Salinity under Irrigation Process and Management. Ecology Study. 51. Springer- Verlag, New York.

Yizong, H., Ying, H. and Yunixia, L. (2009). Combined toxicity of copper and cadmium to six rice genotypes (*Oriza sativa* L.), Journal of Environmental Sciences, **21(5),** 647-653.