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Investigation of Zinc Release Kinetics in an Agricultural Calcareous Soil as Influenced by Applied Organic Materials and Salinity Using Mathematical Models

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ABSTRACT

Desorption of Zinc from soil is one of the important factors that control Zn bioavailability. To investigate the effects of salinity and organic matter on the kinetic release of Zn in a calcareous soil under maize cultivation, an experiment was carried out in greenhouse condition as a 3×4 factorial arranged as completely random design with 3 replications. Factors included three salinity levels (0, 15 and 30 Meq kg^{-1} salt supplied as NaCl, $CaCl_2$ and $MgCl_2$ with 3:2:1 proportion, respectively) and four organic matter treatments [without organic matter, cow manure (2 % w/w), wheat straw (2 % w/w) and cow manure + wheat straw (1:1 ratio)]. Soil samples were extracted using DTPA extractant for periods of 0.5, 1, 2, 6, 12 and 24 hours. The organic matter treatments increased the magnitude of released Zn compared to control (without organic matter). The most and the least increase observed in CW (2.3 folds) and WS (19.7 %) treatments respectively. Zinc release rate increased compared to control and the highest increase observed in CM+WS (2.7 folds) treatment. Zinc release rate was decreased and the magnitude of released Zn was increased by increasing of salinity levels. Simple Elovich equation was determined as the best kinetic model for describing released Zn. The possible mechanism that controls the Zn release from calcareous soil could be through diffusion.

Keywords: Elovich equation, diffusion, cattle manure, wheat straw..

INTRODUCTION

Zinc (Zn) is an important nutrient element for humans and plants that controls many biochemical and physiological functions of living organisms. Zinc deficiency is common in high pH, low organic matter, carbonatic, saline and sodic soils (Rattan and Sharma, 2004). Salinity is a major abiotic environmental stresses that limits growth and production in arid and semi-arid regions of the world. Bioavailability of Zn is low in calcareous and saline soils having high levels of pH and calcium (Alloway, 2004). Crop residues and bestial waste are usually cheap and easily accessible organic residues whose application to agricultural soil could lead to soil improvement. However, they may also influence the distribution of Zn between different fractions (Clement and Bernal, 2006). Ramos (2006) reported that the addition of composted manure (2 % w/w) to soil caused the Zn-DTPA extractable to significantly increase about 72 % over similar untreated soil.

Zinc uptake by plants requires the release of Zn from the adsorption surface sites of soil particles or through the dissolution of minerals containing Zn (Uygur and Rimmer, 2000). Thus, the release rate of Zn into soil solution is a very important factor in the regulation of Zn supply for

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plants. Diethylene triamine pentaacetic acid (DTPA) extractant is typically used to estimate Zn availability in calcareous soil (Lindsay and Cox, 1985). The influence of organic matter on the Zn availability using DTPA extractant was previously evaluated (Ramos, 2006; Karaca, 2004) but less attention has been paid to kinetics of Zn release by DTPA extractant over time by addition of organic matter residue. Zahedifar et al. (2012) showed that the addition of manure (10 g kg^{-1} soil) in some calcareous soil increased the rate of Zn desorption from soil. Few reports on the effects of salinity on the availability and desorption kinetics of Zn are available (Ravikovitch *et al*., 1968; Page *et al*., 1996; Qadir *et al.,* 1997). Rupa *et al*. (2000) reported that increasing the salt concentration led to increase Zn desorption from soil due to ion competition on soil exchangeable sites. Different kinetic equations have been used to describe the release kinetics of nutrients (Sparks, 1989). Reyhanitabar and Gilkes (2010) found that the power function model was the best equation to describe the release of Zn from some calcareous soil of Iran, whereas Baranimotlagh and Gholami (2013) stated that the best model for describing Zn desorption from 15 calcareous soils of Iran was the first-order equation.

Therefore, a greenhouse experiment was carried out to study the effects of salinity and organic matter on Zn release pattern, determination of the best kinetics models to describe Zn release from a calcareous soil after corn cultivation and the magnitude and release rate of Zn using constants of superior kinetics models.

MATERIALS AND METHODS

Soil characteristics

A composite sample of bulk soil from the surface horizon (0-30 cm) of a calcareous soil from southern part of Iran was collected, air dried, passed through 2 mm sieve, and thoroughly mixed. Routine soil analysis (Table 1) were performed to determine soil texture by hydrometer method (Gee and Bauder, 1986); pH of saturated paste (Thomas, 1996); electrical conductivity (EC_e) of saturation extract (Rhoades, 1996); organic carbon (OC) by oxidation with chromic acid and titration with ferrous ammonium sulfate (Nelson and Sommers, 1996); calcium carbonate equivalent (CCE) by neutralization with hydrochloric acid and titration with sodium hydroxide (Loeppert and Suarez, 1996); available phosphorous (P), potassium (K), and zinc (Zn) by extracting them with sodium bicarbonate (Olsen *et al.* 1954), ammonium acetate (Helmke and Sparks, 1996), and diethylene triamine pentaacetic acid, DTPA (Lindsay and Norvel, 1978) and determining their elemental concentrations by spectrophotometry, flame photometry and atomic absorption, respectively.

Organic matter characteristics

The organic matters used in this study were cattle manure (CM) and wheat straw (WS) that differed in zinc content and other properties. Organic matters were air-dried and analyzed for some chemical characteristics. Both pH and EC were measured in 1:5 organic matter and water suspension. Standard methods of analysis were performed to measure organic carbon (Nelson and Sommers, 1996), total nitrogen (Bremner, 1996) and total phosphorous (Chapman and Pratt, 1961), respectively. The concentration of Zn was measured with an Atomic Absorption spectrometer after ashing at about 500-550 ºC and dissolving the ash into 20 % HCl (Table 2).

Greenhouse pot experiment

A factorial experiment as completely randomized design was set up with three replications. Factors included three salinity levels (0, 15 and 30 Meq kg^{-1} salt supplied as NaCl, $CaCl_2$ and $MgCl_2$ with 3:2:1 proportion, respectively) and four organic matter treatments [without organic matter(C), cow manure (2 % w/w) (CM), wheat straw (2 % w/w)(WS) and cow manure + wheat straw (1:1

ratio)(CM+WS)]. The experiment was conducted in the greenhouse of agriculture college of Shahid Chamran University, Ahvaz, Iran. Separate plastic bags were filled by 7 Kg weight samples of the collected soil and then, organic treatments based on aforementioned experimental design were added to Soil. Then, the soil in the plastic bags was mixed thoroughly and transferred into 8 Kg plastic pots. Soil moisture was maintained at field capacity for two weeks by distilled water. Then, nitrogen (N), phosphorous (P), and potassium (K) were added to soils supplied as urea (400 mg kg^{-1} soil), simple superphosphate (200 mg kg^{-1} soil) and potassium sulphate (100 mg kg^{-1} soil) based on soil test results respectively. Seven corn seeds (*Zea mays* L. cv. Hybrid 704) were planted at about 2 cm soil depth. Three weeks after emergence, plants were thinned to two plants per pot. . Afterwards, to prevent osmotic stress due to salinity, the amount of each salt at each salinity level was gradually added to irrigation water only during the fourth week of plant growth. During the experimental period, distilled water (without drainage) was used to maintain moisture content about 80 % of field capacity by regular weighting. Pots with no plants were used as a negative control for soil salinity levels during the experiment. Range of soil saturated electrical conductivity (EC_e) in S_0, S_1 and S_2 treatments during the experiment were (1.9-2.2), (4.6-5.5) and (7.8-8.6) ds m^{-1}, respectively. At day 70, the plants were uprooted from soil. Then, the rhizospheric soil was air-dried, grinded, sieved with 2 mm sieve, thoroughly mixed and transported to the laboratory for testing of zinc release kinetics.

Kinetics study

Release kinetics study was carried out using DTPA solution (Linsay and Norvel, 1978), containing 0.005 mol L^{-1} DTPA, 0.1 mol L^{-1} triethanolamine, and 0.01 mol L^{-1} CaCl2 at pH = 7, as an extractant as follows: 10 g triplicates of each soil sample/ a treatment were placed in a 50-mL centrifuge tube and extracted with 20 mL of DTPA extractant on an end over-end circulatory shaker for periods of 0.5, 1, 2, 6, 12, and 24 h at 25±2 ºC. After shaking, the samples were centrifuged immediately for 10 min and supernatants were filtered through Whatman filter paper No. 42. The filtrate was analyzed for Zn using an atomic absorption spectrometer (AAS) equipped with an air-acetylene flame at 213.9 nm wavelength. Cumulative Zn released (q) as a function of time (T) was evaluated using seven different kinetic models (Table 3). A relatively high values of coefficient of determination (r^2) and low values of standard error of estimate (SEE) were used as criteria for the selection of the best fitted models. Standard errors of estimate were calculated as follows:

$$SE = [\Sigma (q - q^*)^2 / (n - 2)]$$

Where q and q* represent the measured and predicted Zn released, respectively and n is the number of observations. Various Zn release rate parameters were subsequently obtained from fitted equations.

Statistical analysis

Statistical analysis of data was done using MSTATC package (Mstatc, 1991). Comparison between means was performed using Duncan's multiple range test (DMRT) at the significant level of $P < 0.05$. Also, charts were drawn by excel computer package.

RESULTS AND DISCUTION

Zinc release pattern

Investigation of Zn release patterns showed that the control and all treated soils had a uniform pattern of Zn release. Overall, Zn release patterns were generally characterized by an initial fast reaction at first two hours, followed by slower continuing reaction. For example, Zn release pattern at S_2 salinity level as affected by different organic treatments is shown in figure 1. This is in agreement with results reported by Dang *et al*. (1994) and

Zahedifar *et al*. (2010) for Zn and Ghasemi-Fasaei *et al*. (2009) for manganese (Mn). Average of the released zinc in the first two hours was 76 % (Table 4). Also, there was a significant positive correlation (0.99^{**}) between available zinc (released by DTPA during 2 hr) with total amount of released zinc during 24 hours. Therefore, release of zinc from soil was initially rapid (2 hours) and then continued with a slower rate. It seems likely that the release of zinc is controlled by two different mechanisms; two-step process of releases (rapid and subsequent slow) is attributed to the existence of places with different energy (Lehmann and Harter, 1984). The initial rapid release of heavy metals from soil represents the release of these elements from water-soluble forms or absorption places that have low binding energy (exchangeable) and in following, the slow release shows the release of them from the places with higher binding energy and other forms of the elements that are associated with the exchangeable form (Kandpal *et al.,* 2005). Reyhanitabar *et al.,* (2010) investigated zinc adsorption of some calcareous soil of Iran, and they concluded that the best model that can explain Zn adsorption onto these soils was two-surface Langmuir model, therefore, the release of zinc can be taken place from two sites with different energy levels. Ghasemi-Phasaei *et al.* (2007) reported that two different mechanisms controlling the release of copper in some calcareous soils of Iran; they claimed that copper initially releases from coarse aggregate or outer surfaces of fine aggregates quickly and subsequently will slowly continue with the diffusion of the inner surfaces of the fine and coarse aggregates.

Fitting of data on kinetic models

Zinc desorption data for the period of one half to twenty four hours were fitted to seven kinetic models (zero order, first order, second order, third order, power function, parabolic diffusion and simple Elovich) in control and treated soils to describe zinc release kinetics. Assessments of models were performed with respect to the determination coefficient (r^2) and standard error of estimate (SEE). Equations that had the greatest amount of r^2 and minimum SEE were selected as the best models to describe zinc release kinetics (Havlin *et al.,* 1985). The mean and the range of r^2 and SEE of applied kinetic equations are shown in table 5. In order-kinetic models (zero, first, second and third orders), by increasing of reaction times from zero to three, r^2 was reduced. Also, SEE in the third order-kinetic model was greatest. This indicates that the efficiency of order-models to describe the release of Zn is decreased by increasing the reaction time, so, in this experiment; order-kinetic models didn't have good description of Zn release from soil. This is consistent with results of Dang *et al.,* (1994) who reported that desorption of Zn from vertisols was poorly described by order kinetic models. Respectively, Simple Elovich, power function and parabolic diffusion models had the highest r^2 and the lowest SEE, so, these models had a good estimation of zinc release from soil. These results are in close agreement with the findings of Dang *et al.,* (1994) who reported that the appropriate kinetic models to describe Zn release from their studied vertisols were power function, parabolic diffusion and simple Elovich equations. Also, Zahedifar *et al.,* (2010) revealed that the two-constant rate, parabolic diffusion and simple Elovich equations were the best models for describing Zn desorption in their studied calcareous soils. Reyhanitabar and Karimian (2008) observed that the power function and simplified Elovich were the best equations used to describe copper (Cu) desorption from some calcareous soils of Iran. Ghasemi-Phasaei *et al.,* (2009) concluded that simplified Elovich, power function and parabolic diffusion equations were the best fitting equations to describe Mn desorption in some highly calcareous soils of Iran. Reyhanitabar and Gilkes (2010) reported that conformity of Zn release data to both parabolic diffusion and Elovich kinetic models represents a possible control of Zn release from soil by diffusion phenomena. Aharoni *et al.*, (1991) stated that conformity of release data to the Elovich equation could suggest a heterogeneous diffusion process. Pavlatou and Polyzopoulos (1988) reported that the Elovich equation applies to the reactions that are controlled by diffusion phenomena. Havlin *et al.,* (1985) argued that conformity of release data to both two-constant rate and parabolic diffusion kinetic models, indicating the presence of more than one mechanism for controlling the release of the elements. Among the three selected models, simplified Elovich based on the highest r^2 (0.95) and the lowest SEE (0.049), was the top model for describing Zn release. Given the above, it probably seems that diffusion from two surfaces with different absorption energy controls desorption of Zn from our studied soil; so that, a quick diffusion mechanism from soil particles surfaces with low absorption energy is done initially and subsequently, slow diffusion from the inner surfaces with high bond energy will be prevail.

Effect of organic matter and salinity on zinc desorption using constants of two selected kinetic models

Because of Zn release from soil was possibly controlled by diffusion phenomena, so, the effects of organic matter and salinity on Zn desorption kinetic were investigated by the use of constants of parabolic diffusion and simplified Elovich models which are affected by diffusion phenomena. In parabolic diffusion equation, q_0 and K_p constants, indicate the amount of initial Zn release at $t_= 0$ and diffusion rate constant of Zn respectively. The main effects of salinity and organic matter and their interactions on q_0 constant were statistically significant at $p \leq 0.01$ (Table 6).

The amount of q_0 constant was increased by increasing of salinity levels significantly. Also, this constant was significantly increased by application of all three organic matter treatments compared to control. The highest increase observed in CM treatment (227 %) and the lowest increase was in the WS treatment (Table 7). This may be attributed to the greater contribution of mineralized Zn by CM and its Zn content. At S_0 and S_1 salinity levels, the amount of q_0 constant was in the order: CM > CM+WS > WS > C while at S_2 salinity level was as CM > CM+WS > WS = C. Generally, the application of salinity and organic matter increased the magnitude of released Zn in the soil (table 7). The main effects of salinity and organic matter treatments on K_p constant were statistically significant (at $p \leq 0.01$) while their interaction effects weren't significant (Table 6). The amount of K_p constant was significantly decreased by increasing of salinity levels, so that, from 0.188 (mg kg^{-1} $hr^{-0.5}$) at S_0 salinity level reached to 0.177 (mg $kg^{-1}hr^{-1}$) at S_2 salinity level. Also, this constant was increased by application of all three organic treatments compared to control significantly. The highest increase was in CM+WS treatment and the lowest increase observed in WS treatment (Table 7), therefore, the applied organic materials caused the Zn release rate to increase and salinity caused it to reduce.

In simplified Elovich model, a_e and $1/\beta$ constants showed the immediate or initial Zn release rate constant and Zn release rate coefficient respectively. The main effects of salinity and organic matter treatments and their interactions on a_e constant were statistically significant at $p \leq 0.01$ (Table 6). By increasing the levels of salinity, the amount of a_e constant was significantly increased. Also, the application of all organic treatments caused a_e constant to increase compared to control significantly (Table 8). The highest increase was in the CM treatments while the lowest increase observed in the WS treatment. In general, the magnitude of released Zn was increased by application of organic matter and salinity treatments (Table 8). The main effects of salinity and organic matter and their interactions on 1/β constant were statistically significant at $p \leq 0.01$ (Table 6). 1/β constant was significantly reduced by increasing the levels of salinity. This constant was increased compared to the control significantly by application of all organic treatments. The highest increase observed in CM+WS treatment while the lowest increase was in Ws treatments (Table 8). The interaction effects showed that 1/β constant was reduced by increasing of salinity level, in CM and CM+WS, while in WS, it was increased. Generally, the increase of salinity levels caused the Zn release rate to decrease and application of organic matter caused it to increase.

Zahedifar *et al.,* (2012) reported that there was a positive significant relationship between between EC_e and initial Zn desorption rate constant (a) of two-constant rate equation in fifteen calcareous soils of southern Iran. Furthermore, they concluded that there was a positive significant correlation in their studied soils between soil organic matter (SOM) and Zn release rate of Elovich equation (1/β). Rupa *et al.,* (2000) reported that increasing the salt concentration increased the magnitude of Zn desorption from soil. They argued that it was in resulting ions competition for occupancy of exchangeable sites. Mandal *et al.,* (2000) investigated the effects of moisture regime and organic matter on zinc release in corn and rice cultivation and they stated that Zn release in wetting and drying moisture regime was increased by the application of organic matter but in saturation moisture regime was reduced. Schmitt *et al.,* (2002) reported that the presence of natural organic matter in the soil decreased adsorption of Zn. Shamshad *et al.*, (2014) who investigated the effects of dissolved organic matter from corn straw on the adsorption of Zn, expressed that the distribution coefficient (K) of Zn was reduced by 86 % in the presence of dissolved organic matter in Fronlich equation. It represents strong inhibitory effect of dissolved organic matter on Zn sorption. Sadegh *et al.,* (2010) reported that the amount and release rate of Cu were increased by poultry manure application and were decreased by the application of pistachio compost compared to the untreated soil

CONCLUSION

The research results showed that Zn release patterns in the control and all treated soils were generally characterized by an initial fast reaction at first two hours, followed by slower continuing reaction. Among the tested models, the simple Elovich equation was the best model for describing Zn desorption from the studied soil, however, parabolic diffusion and power function models had also good description of Zn release. It seems that the possible mechanism controlling the Zn release in the tested soil is diffusion phenomena. The magnitude of released Zn was increased compared to the control by the addition of all organic treatments significantly. The highest increase observed in CM treatment and the lowest increase was in the WS treatment. This may be attributed to the greater contribution of mineralized Zn by CM and its Zn content. By application of all organic treatments, Zn desorption rate was increased compared to the control and the highest increase observed in CM+WS treatment. Therefore, results from this study indicated that organic matter not only decreased Zn retention of the soil but also increased Zn release in the soil solution and it can be have a significant impact on the supply of Zn to plants, especially in calcareous soils. In general, Zn desorption rate was decreased by increasing of salinity levels.

Table 1. Some physical and chemical characteristics of the studied soil:

Characteristics	Values
Soil texture	Silty clay loam
pH	7.8
EC (dS m^{-1})	2
OC (%)	0.7
TN (%)	0.06
CCE (%)	43.2
Available Phosphorous (mg kg^{-1})	12
Available potassium (mg kg^{-1})	104
Available Zinc (extracted by DTPA) (mg kg^{-1})	0.5

Note: pH: the negative of the logarithm to base 10 of the activity of the hydrogen ion, EC, electrical conductivity of saturation extract; OC, organic carbon; TN, total nitrogen; CCE, calcium carbonate equivalent

Table 2. Some chemical properties of the organic matters used in this study:

Characteristic	CM	WS
EC (dS m^{-1})	7.2	7.4
pH	7.9	6.5
OC (%)	21	30
TN (%)	2.14	1.4
TP (%)	0.58	0.08
TZn (mg kg^{-1})	203	18

Note: EC, electrical conductivity of saturation extract; OC, organic carbon; TN, total nitrogen; TP, total phosphorous; TZn, total zinc; CM, cattle manure; WS, wheat straw.

Table 3. Kinetic models used to describe time -(t) dependent cumulative amount of Zn release (q_t) from soil

Model	Equation	Parameters
Zero order (Martin and Sparks, 1983)	$q_t = q_o - k_o t$	k_o, zero-order rate constant (mg Zn $kg^{-1}s^{-1}$)
First order (Martin and Sparks, 1983)	$Ln\ q_t = Lnq_0 - k_1 t$	k_1, first-order rate constant (s^{-1})
Second order (Martin and Sparks, 1983)	$1/q_t = 1/q_o - k_2 t$	k_2, second-order rate constant [(mg Zn $kg^{-1})^{-1}$]
Third order (Martin and Sparks, 1983)	$1/q_t = 1/q_0^2 - k_3 t$	k_3, third-order rate constant [(mg Zn $kg^{-1})^{-2}$]
Parabolic Diffusion (Havlin *et al*., 1985)	$q_t = q_o + k_p t^{0.5}$	K_p, diffusion rate constant (mg Zn $kg^{-1}h^{-0.5}$)
Power function (Havlin *et al*., 1985)	$q_t = at^b$	a, initial Zn desorption rate constant

		(mg Zn $kg^{-1}h^{-1})^b$ and *b*, desorption rate coefficient [(mg Zn $kg^{-1})^{-1}$]
Simple Elovich (Havlin *et al*., 1985)	$q_t = a_e + 1/\beta \ln t$	a_e, initial Zn release rate constant (mg Zn kg^{-1}) $1/\beta$, zinc release rate coefficient (mg Zn kg^{-1} h^{-1})

Table 4. The amount of Zn release (mg Zn kg^{-1} soil) at 2 and 24 hours and their ratio in different treatments:

Treatments	Zinc release within 2 hours	Zinc release within 24 hours	The ratio of zinc (2hr) to zinc (24hr)
CS_0	0.68	0.85	0.80
CS_1	0.72	0.90	0.80
CS_2	0.79	0.91	0.72
$(WS)S_0$	0.80	0.99	0.81
$(WS)S_1$	0.86	1.08	0.79
$(WS)S_2$	0.87	1.08	0.80
$(CM)S_0$	2.07	2.84	0.73
$(CM)S_1$	2.30	2.94	0.78
$(CM)S_2$	2.38	3.01	0.79
$(CM+WS)S_0$	2.12	2.95	0.72
$(CM+WS)S_1$	2.15	2.97	0.72
$(CM+WS)S_2$	2.22	3.05	0.73
Mean	**1.50**	**1.96**	**0.76**

Note: C, control, S_0, without salt; S_1, 15 Meq salt kg^{-1} soil; S_2, 30 Meq salt kg^{-1} soil; CM, cattle manure; WS, wheat straw.

Table 5. The range and the mean of coefficients of determination (r^2) and standard error of estimate (SEE) of applied kinetic models associated to all treatments

	r^2		SEE	
Kinetic models	**Range**	**Mean**	**Range**	**Mean**
Zero order	0.57-0.86	0.75	0.077-0.25	0.153
First order	0.49-0.81	0.68	0.079-0.23	0.123
Second order	0.38-0.76	0.62	0.038-0.47	0.143
Third order	0.30-0.70	0.56	0.037-1.96	0.425
Parabolic diffusion	0.74-0.95	0.87	0.053-0.15	0.096
Power function	0.79-0.99	0.93	0.015-0.14	0.052
Simple Elovich	0.87-0.99	0.95	0.021-0.082	0.049

Table 6. Mean squares of different treatments and their interactions on constants of selected kinetic models

Source of variations	DF	q_0	K_p	a_e	1/β
salinity	2	0.082**	0.001**	0.068**	0.001**
Organic matter	3	3.734**	0.115**	5.048**	0.137**
Salinity × organic matter	6	0.008**	0.001^{ns}	0.006**	0.001**
Error	24	0.001	0.000001	0.001	0.000001
% CV		3.31	6.75	2.27	5.48

Note: **, * are significant at 1 and 5 % probability level, respectively and ns, not significant; DF, degree of freedom; CV, coefficient of variation; q_0 and K_p, constants of parabolic diffusion equation in (mg Zn kg^{-1}) and (mg Zn kg $h^{-0.5}$); a_e and 1/β, constants of simple Elovich equation in (mg Zn kg^{-1}) and (mg Zn kg^{-1} h^{-1}).

Table 7. Effects of salinity and organic matter on kinetic constants of parabolic diffusion model

	S_0	S_1	S_2	
		q_0		
C	0.463 g	0.539 f	0.621 e	0.541 D
WS	0.627 e	0.653 e	0.664 e	0.648 C
CM	1.635 c	1.826 a	1.858 a	1.773 A
WS + CM	1.518 d	1.631 c	1.754 b	1.634 B
	1.061 C	1.163 B	1.224 A	
		K_P		
C	0.08999 g	0.08026 i	0.06624 j	0.07883 D
WS	0.08327 h	0.09021 g	0.07986 i	0.08445 C
CM	0.266 d	0.237 f	0.256 e	0.253 B
WS + CM	0.315 a	0.293 b	0.286 c	0.297 A
	0.188 A	0.175 B	0.171 C	

Note: Numbers followed by same letters in each column and rows are not significantly (P<0.05) different according to DMRT; C, control; CM, cattle manure; WS, wheat straw S_0, without salt; S_1, 15 Meq salt kg^{-1} soil; S_2, 30 Meq salt kg^{-1} soil; q_0 and K_p, constants of parabolic diffusion equation in (mg kg^{-1}) and (mg kg $h^{-0.5}$).

Table 8. Effects of salinity and organic matter on kinetic constants of Simplified Elovich model

	S_0	S_1	S_2	
		a_e		
C	0.541 g	0.610 f	0.677 e	0.609 D
WS	0.703 e	0.738 e	0.747 e	0.729 C
CM	1.884 c	2.054 a	2.096 a	2.011 A
WS + CM	1.814 d	1.906 c	2.019 b	1.913 B
	1.236 C	1.327 B	1.385 A	
		1/β		
C	0.1057 g	0.09294 k	0.07902 l	0.07883 D
WS	0.09489	0.1001 i	0.1007 h	0.08445 C
CM	0.2970 d	0.2590 f	0.2870 e	0.253 B
WS + CM	0.3490 a	0.3277 b	0.3160 c	0.297 A
	0.211 A	0.194 B	0.195 B	

Note: Numbers followed by same letters in each column and rows are not significantly ($P<0.05$) different according to DMRT; C, control; CM, cattle manure; WS, wheat straw; S_0, without salt; S_1, 15 Meq salt kg^{-1} soil; S_2, 30 Meq salt kg^{-1} soil; a_e and 1/β, constants of simple Elovich equation in (mg Zn kg^{-1}) and (mg Zn kg^{-1} h^{-1}).

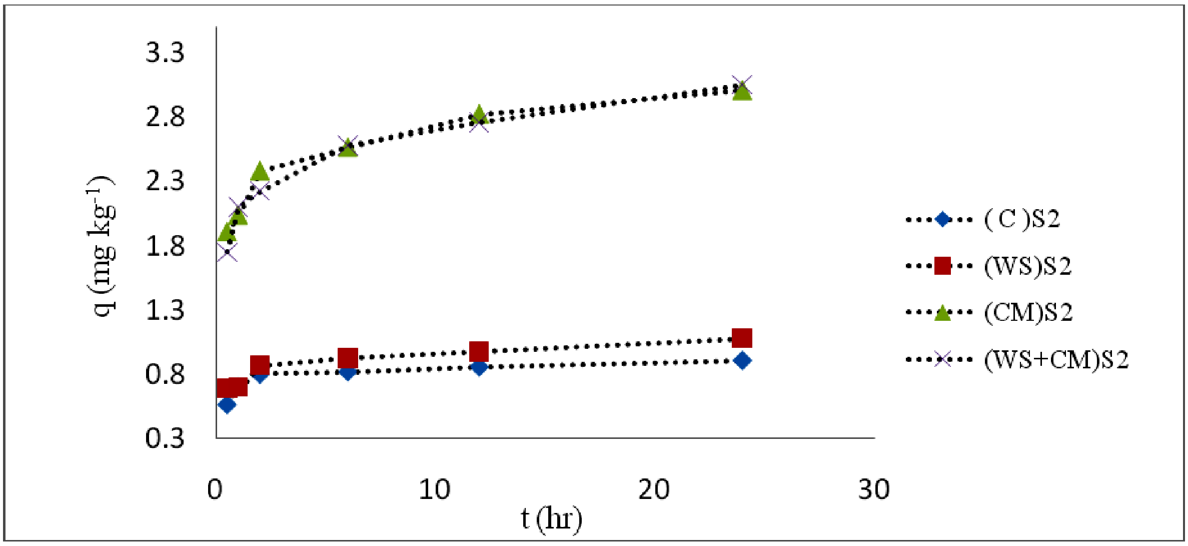

Figure 1. Zinc release pattern at S_2 salinity level as influenced by different organic treatments. C, control; WS, wheat straw; CM, cattle manure; q, the magnitude of zinc desorption; t, time; S_2, 30 Meq salt kg^{-1} soil.

REFERENCES

Aharoni, C., Sparks, D.L., Levinson, S., Revina, I. 1991. Kinetics of soil chemical reactions: Relationship between empirical equations and diffusion models. ***Soil Sci. Soc. Am. J***. 55:1307-1312.

Alloway, B. J. 2004. Zinc in soils and crop nutrition**.** ***International Zinc Association*** (IZA). http://www. Zinc-crop.org, pp. 128.

Alloway, B. J. 2009. Soil factors associated with zinc deficiency in crops and humans. ***Environ. Geochem. Health***. 31:537–548.

Baranimotlagh, M., Gholami, M. 2013. Time dependent zinc desorption in some calcareous soils of Iran. ***Pedosphere,*** 23(2):185-193.

Bremner, J. M. 1996. Nitrogen- Total. P. 1085- 1122. In: D. L. Sparks. et al., (eds) Methods of Soil Analysis. Part III. 3rd ed, ***Am. Soc. Argon***., Madison, WH.

Chapman, H. D., Pratt D. F. 1961. Method of analysis for soil, plant and water. ***Univ. Calif., Div Agric. Sci.*** p. 60-62.

Clement, R., Bernal, M. P. 2006. Fractionation of heavy metals and distribution of organic carbon in two contaminated soils amended with humic acids. ***Chemosphere***, 64:1264-1273.

Dang, Y. P., Dalal, R. C., Edwards, D. G., Tiller, K. G. 1994. Kinetics of zinc desorption from Vertisols. ***Soil Sci. Soc. Am. J.*** 58:1392–1399.

Havlin, J. L., Westfall, D. G., Olsen, S. R. 1985. Mathematical models for potassium release kinetics in calcareous soils. ***Soil Sci. Soc. Am. J***. 49:371–376.

Helmke, P. A., Sparks, D. L. 1996. Lithium, sodium, potassium, rubidium, and cesium. In Methods of soil analysis, part 3, 3rd ed., ed. D. L. Sparks et al., 551–574. ***Madison, Wisc.:USA***.

Gee, G. W., Bauder, J. W. 1986. Particle-size analysis, hydrometer method. In *Methods of soil analysis, part 1*, 3rd ed., ed. A. Klute et al., 404–408. ***Madison, Wisc.: USA***.

Ghasemi-fasaei, R., Tavajjoh, M., Oloma, V., Molazem, B., Maftoun, M., Ronaghi, A., Karimian, N., Adhami, E. 2007. Copper release characteristics in selected soils from southern and northern Iran. ***Australian J. Soil Res***. 45:459-464.

Ghasemi-fasaei, R., Maftoun, N., Olama, V., Molazem, B., Tavajjoh, M. 2009. Manganese release characteristics of highly calcareous soils. ***Commun. Soil Sci. Plant Anal***. 40(7-8):1171-1182.

Kandpal, G., Srivastava, P. C., Ram, B. 2005. Kinetics of desorption of heavy metals from polluted soils: influence of soil type and metal source. ***Water Air Soil Pollution***, 161: 353–363.

Karaca, A. 2004. Effects of organic wastes on the extractability of Cadmium, Copper, Nickel, and Zinc in soil. ***Geoderma***, 122: 297-303.

Lehmann, R. G., Harter, R. D. 1984. Assessment of copper-soil bond strength by desorption kinetics. ***Soil Sci. Soc. Am. J.*** 48:769-772.

Lindsay, W. L., Cox, F. R. 1985. Micronutrient soil testing for the tropics. ***Fertilizer Res***. 7:169–200.

Lindsay, W. L., Norvell, W. A. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. ***Soil Sci. Soc. Am. J***. 42:421–428.

Loeppert, R. H., Suarez, L. 1996. Carbonate and gypsum. In Methods of soil analysis, part 3, 3rd ed., ed. D. L. Sparks et al., 437–474***. Madison, Wisc.: USA.***

Nelson, D. W., Sommers, L. E. 1996. Total carbon, organic carbon, and organic matter. InMethods of soil analysis, part 3, 3rd ed., ed. D. L. Sparks et al., 961–1010. ***Madison, Wisc.: USA.***

Olsen, S. R., Cole, C. V., Watanabe, F. S., Dean, L. A. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate (USDA Circular 939). ***Washington, D.C.: U.S.*** Government Printing Office.

Mandal, B., Hazra, G. C., Mandal, L. N. 2000. Soil management influences on zinc desorption for rice and maze nutrition***. Soil Sci. Soc. Am. J***. 64:1699-1705.

Maftoun, M., Karimian, N. 1989. Relative efficiency of two zinc sources for maize (Zea mays L.) in two calcareous soils from an arid area of Iran. ***Agronomy***, 9:771–775.

Martin, H. W., Sparks, D. L. 1983. Kinetics of non exchangeable potassium release from two coastal plain soils. ***Soil Sci. Soc. Am. J***. 47:883–887.

MSTATC. 1991. Michigan state university. Wast Lansing.

Michigan, **USA**.

Page, A. L., Changeand, A. C., Adriano, D. C. 1996. Deficiencies and Toxicities of Trace Elements. In: "Agricultural salinity assessment and management" No. 71 (Ed.) Tanji, K. K., pp. 138-160. ***Amer. Soc. Civil Eng.*** New York.

Pavlatou, A., Polyzopoulos, N. A. 1988. The role of diffusion in the kinetics of phosphate desorption: The relevance of the Elovich equation. ***J. Soil Sci***. 39: 425-436.

Qadir, M., Qureshi, R. H., Ahmed, N. 1997. Nutrient Availability in a Calcareous Saline-sodic Soil during Vegetative Bioremediation. ***Arid Soil Res***. 11: 343-352.

Ramos, M. E. 2006. Metals in vineyard soils of the pende area (NE Spain) after compost application. ***J. Environ. Manag***. 78: 209-215.

Rattan, R. K., Sharma, P. D. 2004. Main micronutrients available and their method of use. ***Proceedings IFA International Symposium on Micronutrients***, 1-10.

Ravikovitch, S., Margolin, M., Navrot, J. 1968. Zinc Availability in Calcareous Soils: I. Comparison of Chemical Extraction Methods for Estimation of Plant Availability Zinc. ***Soil Sci.*** 105: 57-61.

Reyhanitabar, A., Karimian, N. 2008. Kinetics of copper desorption of selected calcareous soils from Iran. ***American-Eurasian J. Agric. Environ. Sci***. 4(3): 287-293.

Reyhanitabar, A., Gilkes, R. J. 2010. Kinetics of DTPA extraction of zinc from calcareous soils. ***Geoderma***, 154:289-293.

Reyhanitabar, A., Ardalan, M., Gilkes, R. J., Savaghebi, J. 2010. Zinc sorption characteristics of some selected calcareous soils of Iran. ***J. Agric. Sci. Tech***. 12: 99-110.

Rhoades, J. D. 1996. Salinity: Electrical conductivity and total dissolved salts. In Methods of soil analysis, part 3, 3rd ed., D. L. Sparks et al., 417–436***. Madison, Wisc.: USA.***

Rupa, T. R., Tomar K. P., Damidar Reddy, D., Subba Rao, A. 2000. Time-dependent zinc desorption in soils. ***Commun. Soil Sci. Plant Anal***. 31: 2547-2563.

Sadegh, L., Fekri, M., Gorgin, N. 2010. Effect of poultry manure and pistachio compost on the kinetics of copper desorption from two calcareous soils, ***Arab J. Geosci***. 5: 571-578.

Shamshad, K., Yagou, W., Yiaoyan, Z., Sihai, H., Tao, L., Yilin, F., Qiuge, L. 2014. Influence of dissolve organic matter from corn straw on Zn and Cu sorption to Chinese loess. ***Toxicol. Environ. Chem***. 95(8): 1318-1327.

Sinha, M. K., Dhillon, S. K, Dhillon, K. S. 1977. Zinc chelate reaction in alkaline soils. ***Australian J. Soil Res***. 15:103–113.

Schmitt, D., Taylor, H. E., Aiken, G. R., Roth, D. A., Frimmel, F. H. 2002. Influence of natural organic matter on the adsorption of metals ions onto clay minerals. ***Environ. Sci. Technol***. 36(13):2932-2938.

Strawn, D. G., Sparks, D. L. 2000. Effect of soil organic matter on the kinetics and mechanisms of Pb(II) sorption and desorption in soil. ***Soil Sci. Soc. Am. J***. 64: 144-156.

Sparks, D. L. 1989. Kinetics of soil chemical processes. ***Academic Press***. San Diego. California. USA.

Thomas, G. W. 1996. Soil pH and soil acidity. In Methods of soil analysis, part 3, 3rd ed., D. L. Sparks et al., 475–490. ***Madison, Wisc.: USA.***

Uygur, V., Rimmer, D. L. 2000. Reaction of zinc with iron coated calcite surface at alkaline pH. ***European J. Soil Sci***. 51: 511–516.

Zahedifar, M., Karimian, N., Yasrebi, J. 2010. Zinc desorption of calcareous soils as influenced by applied zinc and phosphorus and described by eight kinetic models. ***Commun. Soil Sci. Plant Anal***. 41: 897–907.

Zahedifar, M., Karimian, N., Yasrebi, J. 2012. Influence of applied zinc and organic matter on zinc desorption kinetics in calcareous soils. ***Archive of Agronomy and Soil Science***, 58(2): 169-178.

استخدام النماذج الرياضية لتقصي تأثير المادة العضوية والملوحة على نشاط تحرر الزنك من الترب الزراعية الجيرية

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ملخص

إن الحد من ادمصاص التربة للزنك يعد من العوامل المهمة لاتاحته للنشاطات البيولوجية. ولدراسة تأثير الملوحة والمادة العضوية على مقدرة تحرر الزنك في الأراضي الجيرية المزروعة بالذرة الصفراء، فقد أجريت تجربة عامليه بتصميم كامل العشوائية (3 × 4). وشتملت عوامل الدراسة على ثلاثة مستويات من الملوحة (صفر، 15، 30 ملي مكافئ/كغم) مضافة على شكل NaCl، $CaCl_2$، $MgCl_2$، بنسب 1:2:3 على التوالي بالإضافة إلى أربعة معاملات من المادة العضوية كالآتي بدون إضافة، اضافة زبل أبقار (2% وزن/وزن)، قش قمح (2% وزن/وزن)، زبل ابقار + قش قمح (بنسبة 1:1). تم استخلاص الزنك باستخدام DTPA عند الفترات الزمنية الآتية: 0.5، 1، 2، 6، 12، 24 ساعة. أدت إضافة المادة العضوية إلى زيادة تحرر الزنك بالمقارنة مع الشاهد (بدون إضافة). كانت الزيادة في الزنك المتحرر 2.3 ضعف و 19.7% لكل من المعاملات زبل الابقار وقش القمح على التوالي. لقد تناقص معدل تحرر الزنك بينما زاد المقدار التحرر نتيجة لزيادة مستويات الملوحة. كانت معادلة Elovich من الدرجة الأولى هي النموذج الانسب في وصف تحرر الزنك. إن الآلية المحتملة التي تنظم تحرر الزنك من الترب الجيرية هي من خلال الانتشار.

الكلمات الدالة: معادلة Elovich، الانتشار، زبل الابقار، قش القمح.

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