Effect of Manures and Vermicompost on Zinc Release Kinetics in a Calcareous Soil Grown *Ocimum Basilicum* L.

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ABSTRACT

Desorption of zinc (Zn) from soil is important to determine the bioavailability and toxicity Zn in soil. The objective of this study was to evaluate the effect of organic compounds [cow (CM) and sheep manures (SM) and vermicompost (V)] on Zn desorption from a cultivated calcareous soil and determine the best models for description of the Zn release. Zinc release (using DTPA for 20–1440 minute at 25 ± 2°C) in soil amended with 2% CM, SM, and V were investigated in a completely randomized design with three replications. Basil (*Ocimum Basilicum* L.) seeds were cultivated in each pot for 90 days. Seven kinetic models were evaluated to describe the rate of Zn desorption in soil after basil harvesting. Results showed that Zn release from soil samples increased with increasing of time. Zinc release was rapid at first and then became slower until equilibrium was approached. Cumulative Zn desorption in organic compounds amended soils especially vermicompost was higher than unamended soil and simple Elovich and two-constant rate were the best equations to description of Zn release from studied soils.

Keywords: Zinc release, kinetics models, organic compounds

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INTRODUCTION

Zinc (Zn) deficiencies are common in plants cultivated in calcareous soils, although the Zn content of these soils is no less than that of non-calcareous soils (Akay and Doulati, 2012). Metal concentration in soil solution and their bioavailability is controlled by sorption–desorption reactions at the surface of soil fractions (Khater and Zaghloul 2002). Uptake of elements such as Zn by plants leads to depletion of elements in soil solution and consequently net elements release from soil solid to liquid phase. Therefore, in addition to the quantity of reserved elements in the soil, the amount of soluble elements at any time largely depends on the rate of elements release from the soil particles into the soil solution (Shariatmadari *et al.*, 2006). Hence, studies on the kinetics of Zn release from soil or soil constituents are important to understanding the interaction of element with the soil matrix, predicting and evaluating the availability of Zn in agriculture and studding fertilizer use efficiency (Barrow, 1979; Toor and Bahl, 1999).

In recent years, application of organic fertilizer (sewage sludge, livestock manures, compost and vermicompost) as a source of organic matter other than traditional fertilizers has become popular and efficient for the improvement of soil organic matter and soil properties. Studies have indicated that land disposal of organic waste materials may alter the micronutrient status of the soil by affecting metal solubility or dissociation kinetics (Karaca, 2004). The amount of organic matter in soils affects the binding of metals in soil and speciation in soil solution (Lo *et al.*, 1992). Therefore, studies on the kinetics models of metal release from soil or soil constituents are of importance procedure to describe changes in nutrients availability over time and evaluating toxicity of soil metal in agriculture.

Motaghian and Hosseinpur (2013) investigated the Zn desorption kinetics in wheat (*Triticum Aestivum L.*) rhizosphere in some sewage sludge amended soils and showed that Zn extracted using successive extraction in the rhizosphere were significantly ($P < 0.01$) higher than in the bulk amended soils. The best model for describing extraction data for bulk and rhizosphere soils was the power function equation. Motaghian and Hosseinpur (2014) stated that desorption of Zn in the rhizosphere soil is the primary factor that affects bioavailability of Zn and desorption kinetics of Zn best fitted to first-order, parabolic diffusion, and power function equations. The correlation studies showed that the rate constants in the power function equation were significantly correlated with Zn extracted using DTPA-TEA, AB-DTPA in the bean rhizosphere and the bulk soils. Motaghian and Hosseinpur (2017) showed that amount of cumulative of Zn desorbed in soils amended with cow manure (CM) and vermicompost (VC) was significantly higher than unamended soil. Concentration of Zn desorbed in 0.5 and 1% of CM and VC compared with unamended soil increased 26, 54, 12, and 46%, respectively. Yu and Klarup (1994) reported that the extraction kinetics of iron (Fe), aluminum (Al), copper (Cu) and zinc (Zn) can be well described by the two-constant model. Rupa and Tomar (1999) studied the Zn desorption kinetics as influenced by pH and phosphorus in soils and reported that Zn desorption decreased continuously with increasing of pH from 4.25 to 8.00 in Oxisols. By contrast, Alfisol and Vertisol exhibited maximum Zn desorption at pH 5.50. Thereafter, Zn desorption decreased abruptly at pH 6.75. The Elovich constant (β) indicated that P affects Zn desorption inversely up to pH values 6.75. Reyhanitabar and Karimian (2008) showed that the best model for describing Kinetics of DTPA extraction of Zn from calcareous soils from Iran was the exponential rate equation ($q = a\ t^b$).

Application of organic compounds (OC) such as cow and sheep manure and vermicompost may impact on Zn release kinetics in soil, and studying Zn release in soils treated with OC is important to understand the ability of this materials on Zn desorption in soil solution. Moreover, estimating Zn availability in calcareous soil by DTPA extraction (Lindsay and Cox, 1985) only determines the availability of Zn for plants, whereas the amount of Zn released may change with time and during different stages of plant growth (Sinha *et al.*, 1977). The apparent recovery of Zn by the first crop is very low in calcareous soils, amounting to 5% or less of the applied Zn (Iyengar and Deb, 1977; Darjeh *et al.*, 1991). Since Zn is not leached or otherwise lost from the soil, more than 95% of the applied Zn is, therefore, left in the soil and may be used by the subsequent crops. This is the reason why residual effect of Zn fertilizers has been reported to persist for several years (Brown *et al.*, 1964; Martens and Westermann, 1991).Therefore, the aim of this study was to evaluate the influences of organic compound on Zn release from a calcareous soil of Iran after plant cultivation (to evaluate residual effect of OC and estimate Zn release from soil that may be used for subsequent crops) and determine the best models for description of the kinetics of Zn release in studied soil.

MATERIALS AND METHODS

Study Site, Soil Sampling and Preparation

Surface soil sample (0–30 cm) was collected from Fine, mixed, mesic, Fluventic Calcixerepts (USDA soil taxonomy, Soil Survey Staff, 2014) calcareous soil from agricultural fields located in Bajgah, Bajgah Agricultural Station of Shiraz University, Iran. The soil was air-dried, and then sieved through a 2-mm sieve. Some soil properties such as soil texture, pH, EC, CCE and OM were determined by common standard methods (Table 1): sand, silt and clay fractions by hydrometer method (Gee and Bauder, 1986) and soil texture class using soil texture triangle; soil pH in the saturation extract of soil by glass electrode pH-meter (Thomas, 1996); soil electrical conductivity (EC_e) in the soil saturation extract by EC-meter (Rhoades, 1996); soil calcium carbonate equivalent (CCE) by neutralization with hydrochloric acid and titration with sodium hydroxide (Loppert, 1996); the sodium bicarbonate extractable phosphorus (Available P) according to the Watanabe and Olsen method

(Watanabe and Olsen, 1965), organic matter (OM) by oxidation with chromic acid and titration with ferrous ammonium sulfate (Nelson and Sommers, 1996) and available Fe, Zn, and Cu concentrations were extracted by diethylenetriamine pentaacetic acid (DTPA) extraction (Lindsay and Norvell, 1987), the filtrate was measured by atomic absorption spectrometry (Shimadzu, AA-670 model) for Fe, Zn and Cu concentrations. Total-Zn concentration in the soils was determined in filtered extracts obtained from 2 g sample, which was digested overnight with 12.5 mL 4 M nitric acid (HNO_3) at 80°C (Sposito *et al.*, 1982).

Table 1 Selected chemical and physical properties of the studied soil

Properties	Value
pH in the saturation paste	7.00
Electrical conductivity in the saturation extract (dS m^{-1})	0.54
Texture class	Sandy clay
Organic matter (%)	0.90
Calcium carbonate equivalent (CCE) (%)	40.67
DTPA-extractable Fe (mg kg^{-1})	6.09
DTPA-extractable Cu (mg kg^{-1})	1.09
DTPA-extractable Zn (mg kg^{-1})	0.95
Total Zn (mg kg^{-1})	38.00
Available P ($NaHCO_3$-P) (mg kg^{-1})	9.64

Note: All analytical methods used for every parameter are shown in material and methods

Organic Compound Characterization

The organic compound (OC) used in this study were cow manure (CM), sheep manure (SM) and vermicompost (V). These OC materials usually used in our studied agriculture. Organic compound were air-dried, ground and passed through a 0.25-mm sieve and analyzed for some chemical characteristics (Table 2). pH and EC was measured in 1 to 5 OC to water suspension (Rhoades, 1996; Thomas, 1996). For analysis of Fe, Zn, and Cu, organic compounds were ground and dry-ashed at 550°C. The ash was dissolved in 2 M hydrochloric acid (HCl) and, after passing through filter paper, was used to determine total P by colorimetric method (yellow vanadate) using spectrophotometer and total Fe, Zn, and Cu concentrations was measured by atomic absorption spectrophotometer (Chapman and Pratt, 1961). Available Zn concentrations was extracted by reagent-grade disodium ethylene diamine tetra acetate (Na_2EDTA) extraction (Brown *et al.*, 1971), the filtrate was measured by atomic absorption spectrometry (Shimadzu, AA-670 model) for Zn concentration.

Table 2 Some properties of the organic compounds

Properties	Organic compounds		
	Cow Manure (CM)	Sheep Manure (SM)	Vermicompost (V)
pH (1 : 5 OC : water)	8.7	9.1	7.9
EC (1 : 5 OC : water) (dsm^{-1})	7.4	10.3	1.4
Total P ($mgkg^{-1}$)	259.9	255.6	469.5
Total Fe ($mgkg^{-1}$)	1,274.9	882.9	1,164.3
Total Cu ($mgkg^{-1}$)	11.9	9.3	10.2
Total Zn ($mgkg^{-1}$)	73.2	430.1	200.8
Available Zn extracted with Na_2-EDTA ($mgkg^{-1}$)	28.3	100.2	107.3

Note: All analytical methods used for every parameter are shown in material and methods

Pot Experiment and Organic Compound Treatments

To study Zn release kinetics in soil after plant growth, the pot experiment was conducted in a completely randomized design with three replications. The treatments consisted of CM, SM and V (each at 2% rate), and control, which receive no organic compound were added to each pots. Five hundred grams of air-died soil was used in each pot. To prevent nutrients deficiency in cultivated plant (based on soil analysis), some nutrients were added uniformly to all pots, and mixed. Then, seven *Basil* seeds (*Ocimum Basilicum* L.) were sown in each pot. Pots were kept at 24–25°C and near field capacity for 90 days. After 90 days, plants were harvested and soil samples in each pot were dried, and used for studying Zn release kinetics.

Zinc Release Kinetics Study

To study Zn release kinetics at various time periods in soil after plant cultivation, batch desorption experiment was conducted using DTPA-TEA pH 7.3 extractant (Lindsay and Norvell, 1978). The study time period were from 20–1440 minutes. Five grams of air-dried soil particle size < 2 mm was extracted with 25 ml of mixed solution consisting of 0.005 M Diethylene-Triamine-Pentaacetic-Acid (DTPA), 0.1 M triethanolamine, and 0.01 M $CaCl_2$ at pH 7.3 (Lindsay and Norvell, 1978). The study time period were 20, 40, 60, 120, 180, 480, 960 and 1440 minute periods at 25 ± 2°C. At the end of each time period studied, each sample from each batch was centrifuged immediately for 15 mins at 2,500 rpm (≈1,000×g) and then the supernatant was filtered through Whatman 42 filter paper. The concentration of Zn was determined using AAS (Shimadzu, AA-670 model). Seven different kinetic models were used to describe Zn release from the soils (Table 3). To determine the equation that best described Zn release in these soils, a standard error of estimate was calculated for each equation. A relatively high value of the coefficient of determination (r^2) and low standard error of the estimate (SE) were used as criteria for the best fit (Chien and Clayton, 1980). The standard error was calculated as follows:

$$\mathrm{SE} = \left(\frac{\sum(q - q')^2}{n - 2}\right)^{0.5}$$

Where q and q′ are the measured and calculated amounts of Zn release in soil at time t, respectively, and n is the number of measurements (Steel and Torrie, 1960). Various Zn release rate parameters were subsequently obtained from fitted equations.

Table 3 Equations used to describe Zn release kinetics (Dang *et al.*, 1994)

Model	Equation	Parameters
Zero order	$q_t = q_0 - k_0 t$	k_o, zero order rate constant (mg Zn $kg^{-1}s^{-1}$)
First order	$\ln q_t = \ln q_0 - k_1 t$	k_1, first-order rate constant (s^{-1})
Second order	$\frac{1}{q_t} = \frac{1}{q_0} - k_2 t$	k_2, second-order rate constant [(mg Zn $kg^{-1})^{-1}$]
Third order	$\frac{1}{{q_t}^2} = \frac{1}{{q_0}^2} - k_3 t$	k_3, third-order rate constant [(mg Zn $kg^{-1})^{-2}s^{-2}$]
Parabolic diffusion	$q_t = q_0 - k_p t^{1/2}$	k_p, diffusion rate constant [(mg Zn $kg^{-1})^{-0.5}$]
Simple Elovich	$q_t = \frac{1}{\beta_s} ln(\alpha_s \beta_s) + \left(\frac{1}{\beta_s}\right) ln\, t$	α_s, initial Zn desorption rate (mg Zn $kg^{-1}s^{-1}$), β_s, Zn desorption constant [(mg Zn $kg^{-1})^{-1}$]
Two-constant rate (power Equations)	$q_t = at^b$	α, initial Zn desorption rate constant (mg Zn $kg^{-1}s^{-1})^b$; b, desorption rate coefficient [(mg Zn $kg^{-1})^{-1}$]

Statistical Analysis

Statistical analysis was performed using the SPSS 19.0 software and Microsoft Excel 2010 packages. The difference between means was compared by Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Soil and Organic Compound Properties

Some physico-chemical characteristics of the calcareous soil before treatment and the OC are summarized in Table 1 and 2. Soil was Fine, mixed, mesic, Fluventic Calcixerepts calcareous soil (USDA soil taxonomy, Soil Survey Staff, 2014) with pH of 7 and CCE of about 41%. Electrical conductivity (EC) of saturation extract was 0.54 dS m^{-1}, OM was low, DTPA-extractable Zn and total Zn was 0.95 and 38 mg kg^{-1}, respectively. The OC showed considerably higher levels of P and Zn than in the soil. In contrast to the values obtained for the soil sample, the OC showed higher pH and EC values.

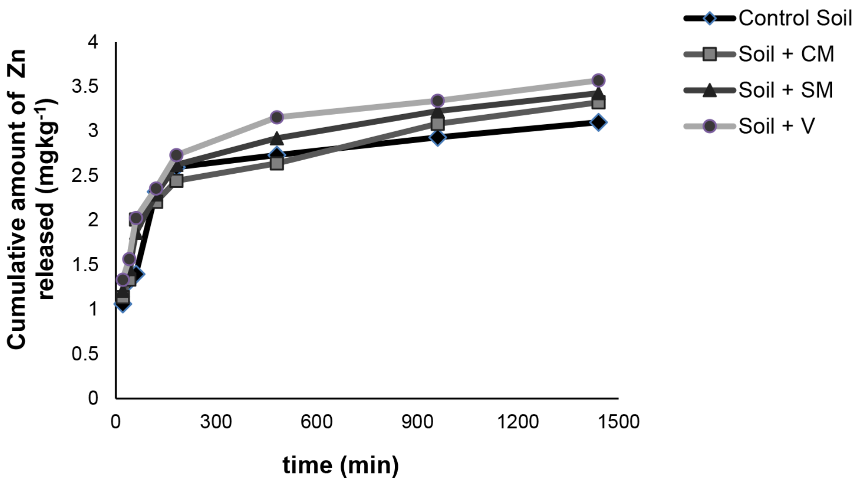

Figure 1 Cumulative amount of Zn release at different times in unamended soil and soil amended with different OC (CM = cow manure, SM = sheep manure, V = vermicompost)

Zinc Release Kinetics

Result on Zn release kinetics were reported in Figure 1. Results showed that the pattern of cumulative Zn release using DTPA TEA pH 7.3 was similar in all treatments and desorption time periods but the amount of Zn release was different between un-amended and soils amended with OC.

The order of Zn release in soil treated samples were soil + V > soil + SM > soil + CM > Control, respectively. The amount of Zn was different in the three organic compounds which may play an important role in controlling the amount of Zn release (Table 2). The concentration of available Zn in V is higher than SM and CM (Table 2), therefore, in comparison with amended soils with V, Zn desorbed in amended soils with SM and CM decreased. Moreover, organic compound might have formed soluble complexes with Zn and enhanced their release as compared to control (Stevenson and Fitch, 1981). Mandal and Hazra (1997) found that organic matter application increased extractability of Zn. Karaca (2004) reported that the DTPA-extractable Zn increased with increasing organic wastes rates that added to soil. Ramadan *et al.* (2008) showed that the Cu, Zn, and Mn availability in soil, increased by application of poultry manure. Sadegh Kasmaei and Fekri (2012) reported that with pistachio compost application, Cu extractability increased. It might be concluded that low molecular weight organic acids originated from soil organic matter decomposition can form soluble complexes with metal cations (Stevenson and Fitch, 1981), and modify the fixation of metals by soil organic matter, and oxides, clays, and enhance their release (Chen *et al.*, 2003). Motaghian and Hosseinpur (2017) showed that amount of cumulative of Zn desorbed in soils amended with cow manure (CM) and vermicompost (VC) was significantly higher than unamended soil.

Our results showed that Zn release from soil samples increased with time from 20 to 1440 min (Figure 1). In all treatments, Zn release was rapid at first and then became slower until equilibrium was received. About 50% of total Zn desorption was released within 120 min, followed by a slower release during the next 1440 min. Therefore, this result could also confirm that two steps desorption process of Zn from soil. Boostani *et al.* (2018) reported that Zn release patterns from calcareous soils were characterized by an initial fast pattern at first 2 h, followed by slower continuing reaction until equilibrium obtained. It seems likely that the release of Zn is controlled by two different mechanisms. Initial faster release of heavy metals from soil may be showed faster desorption of these metals from the water-soluble fraction and the adsorption sites of lower bonding energy (exchangeable fraction), and slower desorption of metals may be indicated the release of metals from the sites of relatively higher bonding energy than the exchangeable form and other chemical pools in dynamic equilibrium with the exchangeable form (Kandpal *et al.,* 2005). Krishnamurti *et al.* (1999) also reported similar involvement of sites of differing reactivity in Cd desorption from soils. The release rates of Zn from soil can be attributed to several different processes. Three common Zn release mechanisms observed in the soils are dissolution of various Zn minerals, release of Zn from mineral surfaces, and release of Zn from organic matter (mineralization). Release rates can vary depending on the mineral surface and sorption mechanisms. The dissolution rate of Zn minerals varies depending on the species, crystallinity and the particle size of the mineral (Sadegh Kasmaei and Fekri, 2012).

Table 4 Coefficient of determination (r^2) and standard error of the estimate (SE) of various kinetic equations

Treatments	Zero order		First order		Second order		Third order		Parabolic diffusion		Simple Elovich		Two-constant rate	
	r^2	SE	r^2	SE	r^2	SE	r^2	SE	r^2	SE	r^2	SE	r^2	SE
Control	0.61	0.54	0.52	0.66	0.44	0.83	0.37	1.43	0.76	0.42	0.92	0.25	0.90	0.33
Soil + CM	0.67	0.55	0.50	0.61	0.36	1.13	0.26	1.57	0.80	0.41	0.96	0.27	0.90	0.32
Soil + SM	0.71	0.49	0.60	0.57	0.48	0.71	0.39	1.70	0.86	0.39	0.98	0.27	0.93	0.37
Soil + V	0.71	0.49	0.61	0.55	0.49	0.83	0.40	1.53	0.86	0.33	0.98	0.13	0.95	0.24

Note: CM = Cow manure, SM = Sheep manure, V = Vermicompost

Data Fitting to Different Kinetic Models

To description Zn release from soils, zero-, first-, second-, and third-order equations, the parabolic diffusion equation, the two-constant rate equation, and the simple Elovich equation were used. To determine the equation that best described Zn release in soil OC amended and control samples, a standard error of estimate (SE) and coefficient of determination (r^2) were calculated for each equation. A relatively high values of r^2 combined with relatively low SE were used for choosing the best fitting models (Chien and Clayton, 1980; Khater and Zaghloul, 2002; Reyhanitabar and Karimian, 2008;).The amount of Zn released from soil samples during 1440 min was poorly described by zero-, first-, second-, and third-order equations (Figure 2), therefore the order kinetic models will not be discussed furthermore. With the increasing order of reaction from zero to third order, the coefficient of determinations (r^2) decreased and SE increased in the soils studied (Table 4).

In all soil samples studied, based on parabolic diffusion equation (Figure 2), indicated that the rate of Zn release was higher in the first 120 min followed by a slower release rate, indicating two different mechanisms are involved. A discontinuity in slope at 120 min was observed in linear form (Figure 2). The trend indicated that probably two different mechanisms because of continuous shaking of soil samples during release experiment are involved (Havlin *et al.*, 1985). Khater and Zaghloul (2002) and Ghasemi Fasaei *et al.* (2006) reported that metal desorbed from macro aggregates or outer surface of micro aggregates in the first quick step are followed by desorption and diffusion of metal from inside macro or micro aggregates. Also, it is possible that the energies of Zn desorption increase exponentially or as a power function as Zn is desorbed by extractor from soil solids and diffuses into the soil solution (Dang *et al.*, 1994).

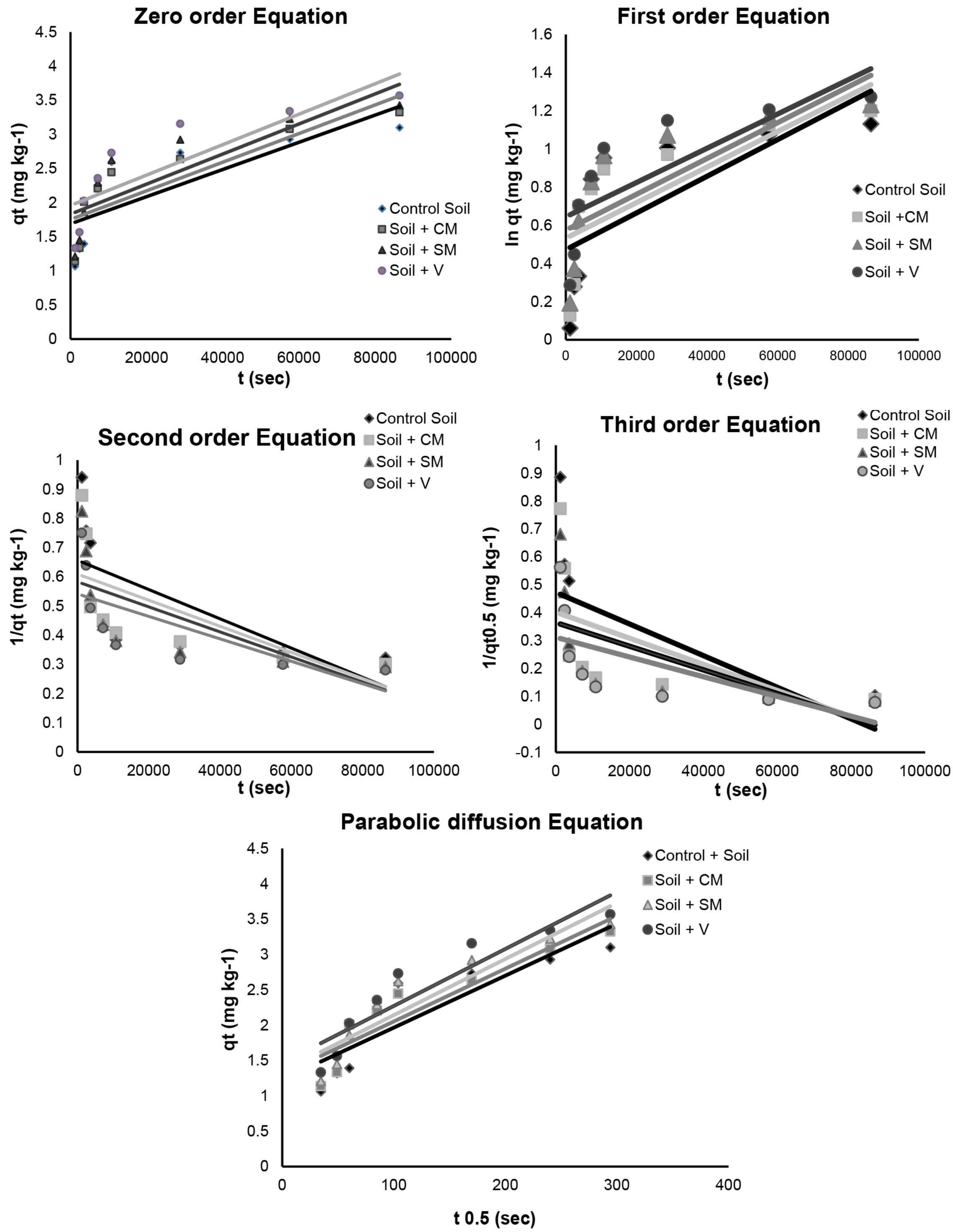

Figure 2 Use of different models to describe cumulative amount of Zn desorbed with time in unamended soil and soil amended with different OC (CM = cow manure, SM = sheep manure, V = vermicompost)

Comparisons of r^2 and SE values of different models in the Table 4 indicated that the best models for describing the data in all studied soils were two-constant rate and simple Elovich equations (Figure 3). So, these models had a good estimation of Zn release from this studied soil. Pavlatou and Polyzopoulos (1988) argued that the Elovich equation applies to the reactions that are controlled by diffusion phenomena. Therefore, it might be diffusion from two surfaces with different adsorption energy controls Zn release from the studied soil; so that, a quick diffusion mechanism from soil particles surfaces with low-absorption energy is made initially and subsequently, slow diffusion from the inner surfaces with high-bond energy will be prevailed. Kuo and Mikkelsen (1980) reported that the Zn desorption reaction can be described by a two constant rate equation, $C = At^{B}$. Rupa and Tomar (1999) concluded that Elovich and Parabolic diffusion equations can described Zn desorption kinetics much better than the other equations. Khater and Zaghloul (2002) concluded that power function, parabolic diffusion, and first order equations were the best-fitted equations used to describe Zn and Cu desorption. The authors should explain what information we can obtain from these fittings.

Table 5 Calculated rate constants for the best kinetic models

Treatments	Simple Elovich		Two-constant rate		
	α_s	β_s	a	b	ab
Control	0.004	2.01	0.195	0.255	0.049
Soil + CM	0.005	2.03	0.245	0.235	0.058
Soil + SM	0.005	1.90	0.246	0.239	0.059
Soil + V	0.006	1.87	0.290	0.229	0.066

Note: α_s = nintial Zn desortion rate of simple Elovich equation β_s = Zn desorption constant of simple Elovich equation, a = initial Zn desorption rate constant of two-constant rate equation b = desorption rate coefficient of two-constant rate equation, respectively.
CM = cow manure, SM = sheep manure, V = vermicompost

Values of the rate constants for the kinetic models that best described Zn release from soil samples are given in Table 5. In the two-constant rate equation, q_t can be differentiated with respect to t, resulting in and when *t = 1*, the previous equation can be written as , and *ab* may be taken as initial desorption rate of soil nutrient. In soil samples with OC treatments, the values of *a* and *ab* constants increased significantly, and the values of *b* constants decreased than the corresponding values in the control soil, and the highest values of *a* and *ab* constants were observed in the vermicompost treatment. The difference in the value of a constant in treated studies soil could be probably attributed to the different Zn characteristics of OC. An increase in the value of a constant and/or a decrease in the value of 'b' constant from two-constant rate equation probably indicates an increase in the rate of desorption from soils (Dang *et al.*, 1994). Therefore, the soil treated with vermicompost had maximum value of a constant and minimum value of b constant and according to the two constant rate equation, the Zn release rate from soil treated with vermicompost was the highest among the other treated soil especially control.

The Elovich model is in the linear form of qt = 1/βs. In αs.βs + 1/βs Int (Simple Elovich equation) was tested by plotting the cumulative Zn released as a function of the log of time, where, qt is the concentration of Zn in the soil (mg kg^{-1}) at any given time, t is the time (s) and αs and βs are the desorption constants (mg kg^{-1}). A linear relationship exists between qt and lnt for each OC treated soil (Figure 3). The values of αs in Elovich equation increased with the application of OC than the corresponding values in the control soil (Table 5). Findings of Chien and Clayton (1980) revealed that the rate of Zn release increased in the simple Elovich equation when the value of α_s increased or β_s decreased. The highest value of αs constant and the lowest value of βs constant were observed in vermicompost treatment, so vermicompost treated soil lead to an increase in the amount of Zn desorbed might be because of higher Zn availability (Table 2). Most Zn deficiency occur in calcareous soils, therefore higher desorption rate usually results in higher availability of metals to plants, OC especially vermicompost may be used in some calcareous soils to increase the uptake of Zn by plants.

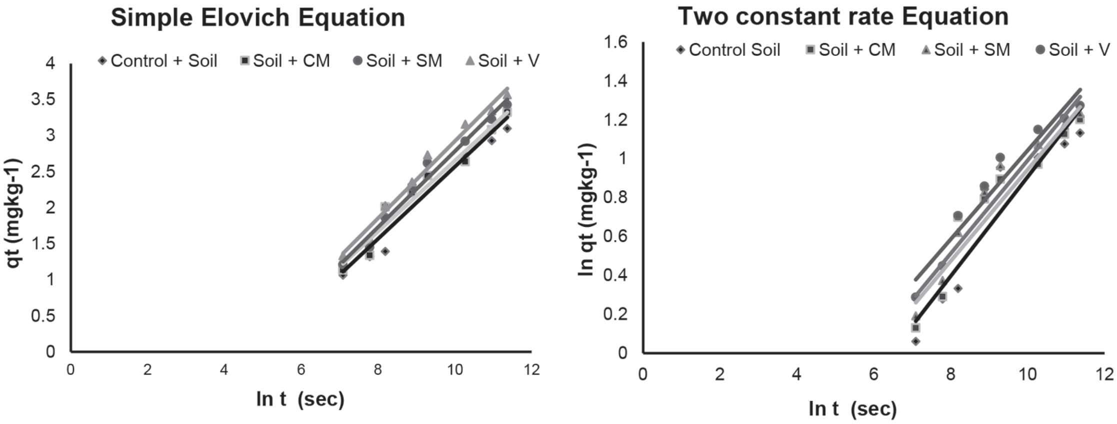

Figure 3 Measured and predicted Zn release as described by Simple Elovich and Two-constant rate equation in soil treated with different OC (CM = cow manure, SM = sheep manure, V = vermicompost) after plant harvesting

CONCLUSIONS

Results of this study showed that Zn release from soil samples were greater in OC treatments (i.e. cow manure, sheep manure and vermicompost) than unamended control soil. Decomposition of the manures and the vermicompost during 90 days in soil might have been a factor that increase zinc release in the treated soils. Also, organic compound might have formed soluble complexes with Zn and enhanced their release.

Release of Zn in the vermicompost treated soil was more than sheep and cow treated soil. It concluded that greater Zn desorption from soil + V than other treatment might be related to higher concentration of available Zn in V than SM and CM. The kinetics of Zn desorption from the treated calcareous soil showed that Zn desorption was characterized by a rapid initial desorption up to 2 h of equilibration, followed by a slower release rate. The initial rapid release of Zn from soil indicates the Zn desorption from readily extractable fractions but the slower phase might be related to a Zn fraction with slower extraction kinetics. Between seven kinetic equations that used and fitted to Zn release data, according to the values of the R^2 and SE, simple Elovich and two-constant rate were the best equations for description of Zn release from soils. Also constant values of the best fitted equations indicated that Zn desorption was higher in soil amended with OC especially vermicompost than the control. Since Zn is not leached or otherwise lost from the soil, more than 95% of the applied Zn is, therefore, left in the soil and may be used by the subsequent crops. Moreover, higher desorption rate usually results in higher availability of metals to plants, vermicompost may be suggested in soil to increase the uptake of Zn by plants. Further experiments are needed to determine the Zn availability and fractionation before and after plant cultivation and in the rhizosphere of plants in soil treated with organic compound

REFERENCES

Akay, A. and B. Doulati. 2012. The effect of soil properties on Zn adsorption. J. Int. Environ. App. Sci. 7: 151–160.

Barrow, N.J. 1979. The description of desorption of phosphate from soils. J. Soil Sci. 30: 259–270.

Brown, A.L., J. Quick and J.L. Eddings. 1971. A comparison of analytical methods for soil zinc. Soil Sci. Soc. Am. Proc. 35: 105–107.

Brown, A.L., B.A. Krantz and P.E. Martin. 1964. The residual effect of zinc applied to soils. Soil Sci. Soc. Am. Proc. 28: 236–238.

Boostani, H.R., M. Najafi-Ghiri, H. Amin and A. Mirsoleimani. 2018. Zinc desorption kinetics from some calcareous soils of orange (*Citrus sinensis* L.) orchards, southern Iran. Soil Sci. Plant Nutr. DOI: 10.1080/00380768.2018.1554951.

Chapman, H.D. and D.F. Pratt. 1961. Methods of Analysis for Soil, Plant, and Water. University of California Division of Agricultural Sciences. pp. 60.

Chen, Y.X., Q. Lin, Y.M. Luo, Y.F. He, S.J. Zhen, Y.L. Yu, G.M. Tian and M.H. Wong. 2003. The role of citric acid on the phytoremediation of heavy metal contaminated soil. Chemosphere. 50: 807–811.

Chien, S.H. and W.R. Clayton. 1980. Application of Elovich equation to the kinetics of phosphate release and sorption in soils. Soil Sci. Soc. Am. J. 44: 265–268.

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

Darjeh, Z., N. Karimian, M. Maftoun, A. Abtahi and K. Razmi. 1991. Correlation of five Zn extractants with plant responses on highly calcareous soils of Doroodzan Dam area, Iran. Iran Agric. Res. 10: 29–45.

Gee, G.W. and J.W. Bauder. 1986. Particle size analysis, pp: 383–409. *In:* A. Klute, (Ed.), Methods of Soil Analysis. American Society of Agronomy and Soil Science Society of America, Madison.

Ghasemi Fasaei, R., M. Maftoun, A. Ronaghi, N. Karimian, J. Yasrebi, M.T. Assad and J.A. Ippolito. 2006. Kinetics of copper desorption from highly calcareous soils. Commun. Soil Sci. Plant Anal. 37: 797–809.

Motaghian, H.R. and A.R. Hosseinpur. 2013. Zinc desorption kinetics in wheat (*Triticum aestivum* L.) rhizosphere in some sewage sludge amended soils. J. Soil Sci. Plant Nutr. 13: 664–678.

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

Iyengar, S.S. and D.L. Deb. 1977. Contribution of soil zinc fractions to plant uptake and fate of zinc applied to the soil. J. Indian Soc. Soil Sci. 25: 426–432.

Jackson, M.L. 1967. Soil Chemical Analysis. Prentice Hall of India Private Limited, New Delhi, India.

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

Karaca, A. 2004. Effect of organic wastes on the extractability of cadmium, copper, nickel, and zinc in soil. Geoderma. 122: 297–303.

Khater, A.H. and A.M. Zaghloul. 2002. Copper and zinc desorption kinetics from soil: effect of pH, pp. 1–9. *In*: 17th World Conference on Soil Science, Thailand, Symposium.

Krishnamurti, G.S.R., P.M. Huang and L.M. Kozek. 1999. Sorption and desorption kinetics of cadmium from soils: influence of phosphate. Soil Sci. 164: 888–898.

Kuo, S. and D.S. Mikkelsen. 1980. Kinetics of zinc desorption from soils. Plant Soil. 56: 355–364.

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

Lindsay, W.L. and W.A. Norvell. 1978. Development of a DTPA soil test for Zn, Fe, Mn, and Cu. Soil Sci. Soc. Am. J. 42: 421–428.

Lo, K.S.L., W.F. Yang and Y.C. Lin. 1992. Effects of organic matter on the specific adsorption of heavy metals by soil. Toxicol. Environ. Chem. 34: 139–153.

Loppert, R.H. and D.L. Suarez. 1996. Carbonate and gypsum, pp. 437–474. *In:* D.L. Sparks *et al.*, (Eds.), Methods of Soil Analysis. Part III. 3rd ed. American Society of Agronomy, Inc: Madison, WI.

Mandal, B. and G.C. Hazra. 1997. Zn adsorption in soils as influenced by different soil management practices. Soil Sci. 162: 713–721.

Martens, D.C. and D.T. Westermann. 1991. Fertilizer application for correcting micronutrient deficiencies, pp. 549–592. *In:* J.J. Mortvedt, F.R. Cox, L.M. Shuman and R.M. Welch (eds.), Micronutrients in Agriculture. 2nd ed. Book Series No. 4. Soil Science Society of America, Madison, WI.

Motaghian, H.R. and A.R. Hosseinpur. 2013. Zinc desorption kinetics in wheat (*Triticum aestivum* L.) rhizosphere in some sewage sludge amended soils. J. Soil Sci. Plant Nutr. 13: 664–678.

Motaghian, H.R. and A.R. Hosseinpur. 2014. Zinc desorption kinetics in bean (*Phaseolus vulgaris* L.) rhizosphere in sewage sludge-amended calcareous soils. Environ. Earth Sci. 71: 965–973.

Motaghian, H.R. and A.R. Hosseinpur. 2017. The effects of cow manure and vermicompost on availability and desorption characteristics of zinc in a loamy calcareous soil. Commun. Soil Sci. Plant Anal. 48: 2126–2136.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon and organic matter. pp. 961–1010. *In:* DL, Sparks, (Eds.), Method of Soil Analysis, Part III. 3rd ed. American Society of Agronomy, Inc: Madison, WI.

Olsen, S.R., C.V. Cole, E.S. Watanabe and L.A. Dean. 1954. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. USDA circular 939, USA Government Printing Office, Washington DC, USA.

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

Ramadan, M.A.E., A.M. El-Bassiony and A.M. Hoda. 2008. Behaviour of some micronutrients in soil and tomato plant organs under different levels and types of fertilizers. Aust. J. Basic Appl. Sci. 2: 288–295.

Reyhanitabar, A. and N. Karimian. 2008. Kinetics of copper desorption of selected calcareous soils from Iran. American-Eurasian J. Agr. Environ. Sci. 4: 287–293.

Rhoades, J.D. 1996. Salinity: electrical conductivity and total dissolved solids, pp. 417–435. *In:* D.L. Sparks, (Ed.). Methods of Soil Analysis, Part III: Chemical Methods. American Society of Agronomy and Soil Science Society of America, Madison.

Rupa, T.R. and K.P. Tomar. 1999. Zinc desorption kinetics as influenced by pH and phosphorus in soils. Commun. Soil Sci. Plant Anal. 30: 1951–1962.

Sadegh Kasmaei, L. and M. Fekri. 2012. Effect of organic matter on the release behavior and extractability of copper and cadmium in Soil. Commun. Soil Sci. Plant Anal. 43: 2209–2217.

Shariatmadari, H., M. Shirvani and A. Jafari. 2006. Phosphorus release kinetics and availability in calcareous soils of selected arid and semiarid topo sequences. Geoderma. 132: 261–272.

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

Soil Survey Staff. 2014. Keys to Soil Taxonomy. 12th ed. Washington (DC): U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS).

Sposito, G., L.J. Lund and A.C. Chang. 1982. Trace metal chemistry in arid-zone field soils amended with sewage sludge, I: fractionation of Ni, Cu, Zn, Cd, and Pb in solid phases. Soil Sci. Soc. Am. J. 46: 260–264.

Steel, R.G.D. and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York, USA.

Stevenson, F.J. and A. Fitch. 1981. Reactions with organic matter, pp. 69–95. *In:* J.F. Loneragan *et al.*, (Eds.). Copper in Soils and Plants. Academic, Sydney, Australia.

Thomas, G.W. 1996. Soil pH and soil acidity, pp. 475–490. *In:* D.L. Sparks (Ed.), Methods of soil analysis Part III, Chemical Methods. Soil Science Society of America, Madison.

Toor, G.S. and G.S. Bahl. 1999. Kinetics of phosphate desorption from different soils as influenced by application of poultry manure and fertilizer phosphorus and its uptake by soybean. Bioresource Technol. 69: 117–121.

Viro, P.J. 1955. Use of ethylene diamine tetra acetic acid in soil analysis. Soil Sci. 79: 459–465.

Watanabe, F.S. and S.R. Olsen. 1965. Test of an ascorbic acid methods for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Am. Proc. 29: 677–678.

Yu, J. and D. Klarup.1994. Extraction kinetics of copper, zinc, iron and manganese from contaminated sedimentusing disodium ethylenediaminetetraacetate. Water Air Soil Poll. 75: 205–225.