

# Phosphorus desorption kinetics in two calcareous soils amended with P fertilizer and organic matter

M. Fekri · N. Gorgin · L. Sadegh

Received: 12 May 2009 / Accepted: 13 December 2010 / Published online: 1 January 2011  
© Springer-Verlag 2010

**Abstract** We studied the effects of poultry manure and pistachio compost with and without phosphorus fertilizer on the kinetics of phosphorus desorption in two calcareous soils of Kerman and Koohbanan farms in the southeastern of Iran. For this purpose mono potassium phosphate, at rates of 0, and 100 parts per million of phosphorus, and air-dried manure, at rates of 0 and 4% were mixed with the soils. The soils were incubated at 24–25°C and near field capacity for 90 days in the greenhouse. Afterwards, the desorption of P was studied by the successive extraction with 0.5 M NaHCO<sub>3</sub>. The results of this research indicated that application of OM and fertilizer P combined increased P recovery in each of the extraction time, adding poultry manure and 100 mg phosphorus together to the soils, increased P desorption more than pistachio compost in the soils. The phosphorus desorption rate was initially rapid and then became slower until equilibrium was approached. Kinetic data were best described by power function and simple Elovich equations. Subsequent to these equations, parabolic diffusion equation was also well fitted the time-dependent P desorption data.

**Keywords** Phosphorus · Desorption · Kinetics equations · Organic matter

## Introduction

Application of phosphorus (P) fertilizers in agricultural calcareous soils has introduced some problems mainly because of P adsorption, precipitation, low recovery and accumulation in soil. Decrease in availability of P is suggested to be a complex function of several factors such as: soil chemical composition, amount and reactivity of silicate clays, CaCO<sub>3</sub>, Fe oxides, P addition rates and time (Afif et al. 1993). Organic sources of P are known to increase P availability more than inorganic P fertilizers and enhance efficient use of applied P fertilizer (Mohanty et al. 2006). The synergistic effect of manure application along with P fertilizer on increasing soil test P concentration has been reported by Toor and Bahl (1997); Reddy et al. (1999); Mkhabela and Warman (2005) and Garg and Bahl (2008).

The voluminous literature studies on soil P document the importance of its role in nature. Phosphorus is less abundant in soils than nitrogen and potassium. Total P in surface soils varies from 0.005 to 0.15%. The quantity of total P in soils has little or no relationship to the availability of phosphorus to plants (Havlin et al. 1991; Tisdale et al. 1985). Phosphorus desorption and retention by soils plays a crucial role in both crop production and environmental protection. In 1840s, P was identified as an essential plant nutrient (Jiao et al. 2007). Barrow and Shaw (1975b) suggested that soil phosphate can be considered as accruing in three compartments  $A \leftrightarrow B \leftrightarrow C$ . Compartment A represents phosphate in the soil solution. The equilibrium between A and B is rapid, hence compartment B is defined as containing the phosphate in direct equilibrium with the soil solution. The transfer of phosphate between compartments B and C is much slower and the phosphate is held more firmly in compartment C. Phosphorus desorption

M. Fekri (✉) · N. Gorgin · L. Sadegh  
Department of Soil Science, College of Agriculture,  
Shahid Bahonar University of Kerman, Kerman, Iran  
e-mail: mjdfekri@yahoo.com

N. Gorgin  
e-mail: n\_gorgin2006@yahoo.com

L. Sadegh  
e-mail: leilasadegh@yahoo.com

from soil colloids is one of a series of rate processes that govern P uptake by roots and subsequent utilization in plant growth (Elkhatib and Hern 1988). Therefore, the rate of desorption of P from the solid matrix to maintain the solution P concentration is of importance, because the adsorbed P as such cannot be utilized by plants unless it passes into soil solution by a desorption step (Nagarajah et al. 1968). In addition, the P desorption from soil is a significant risk factor to surface water quality. The movement of phosphorus from agricultural land to surface water can lead to accelerated eutrophication, especially when external pollution is reduced (Correll 1998; Abrams and Jarrell 1995; Xie et al. 2003). Soil P desorption to solution was likely controlled by a combination of Fe (strengite), AL (variscite), and Ca (hydroxyapatite) complexes (McDowell and Sharpley 2003). Also the calcareous soils generally desorbed more P than the acid soils (Raven and Hossner 1994). Crops growing in large region of the world's agricultural soils respond to phosphate fertilization (Bohn et al. 1985). Desorption of P is related to soil P concentration and therefore, strongly influenced by P additions of fertilizers and manures (McDowell and Sharpley 2001). Soil management practices such as the addition of organic matter to the soil may modify the amount of available P found in soil (Sing and Jones 1976). The kinetics of P desorption in soils is a subject of importance in soil and environmental sciences primarily because P uptake by plants spans over time. Therefore, kinetic information is required to properly characterize the P supplying capacity of soils, to design fertilizer P management to optimize efficiency, and to reduce environmental pollution (Skopp 1986). On the other hand, the kinetic investigation of soil P desorption is considered an excellent tool for assessing the status of soil phosphorus and studying the reaction mechanisms (Olsen and Khawneh 1980; Skopp 1986). In many studies of phosphate desorption in soils, it is common to observe that the reaction rate is very rapid at first, and then it declines slowly as the apparent equilibrium is approached (Chien and Clayton 1980; Toor and Bahl 1999; Shariatmadari et al. 2006; Amer et al. 1955; Evans and Jurinak 1976). It seems that the amount and rate of desorption will be affected by the time of prior contact between soil and phosphate (Barrow and Shaw 1975a). Phosphorus desorption kinetics and its sorption by soil are very complex. Several researchers have extensively studied P desorption kinetics from soils and the ability of kinetic models to describe P desorption (Chien and Clayton 1980; Toor and Bahl 1999; Elkhatib and Hern 1988; Yang and Skogley 1992). The parameters of these equations are used to interpret the phosphorus desorption from soils. The relationship between the amount of phosphate desorbed or absorbed and the time has been

described by zero order (Pavlatou and Polyzopoulos 1988), first order equations (Elkhatib and Hern 1988; Pavlatou and Polyzopoulos 1988; Amer et al. 1955), the parabolic diffusion (Evans and Jurinak 1976; Pavlatou and Polyzopoulos 1988; Shariatmadari et al. 2006; Vig and Dev 1979), Elovich equations (Chien and Clayton 1980; Shariatmadari et al. 2006; Raven and Hossner 1994; Sharpley 1983) and power function equations (Kuo and Lotse 1973). These studies have pointed out that P desorption can quite satisfactorily be explained using different kinetics equations, but no single equation can be considered the best for all studies and soils. Relatively little has been reported on the P desorption kinetics in treated organic manure soils. The objectives of this study were: (1) to study different levels of applied P fertilizer on P release from soils, (2) to evaluate the impact of poultry manure and pistachio compost and their interaction with applied P fertilizer on P desorption characteristics, (3) to compare the ability of the zero order, first order, second order, third-order, parabolic diffusion, power function, simple Elovich equations to describe P desorption rate from control and organic matter amended soils, (4) to select the best equation for describing the kinetics of P desorption and (5) to compare the coefficient rates of these equations in two calcareous soils of Kerman in the east-southern Iran. Such information is useful in predicting the fate of added P fertilizer in soils and making reliable P fertilizer recommendations.

## Materials and methods

Two fertilized soil samples were used in this study. Soil samples (0–30 cm) were collected from ShahidBahonar University Research Farm (UF) and Koohbanan farm (KF) from Kerman province in the southeastern Iran. Soil samples were air-dried, ground and passed through a 2-mm sieve for the determination of the soil properties. Some of the properties of the soils are given in Table 1. Particle size was determined by the hydrometer method (Gee and Bauder 1986). Soil pH was determined in the saturation mud of soil using a combination electrode (Thomas 1996). Electrical conductivity ( $EC_e$ ) was measured in the soil saturation extract using a conductivity meter (Rhoades 1996). Olsen-extractable phosphorus (Olsen-P) (Olsen et al. 1954) organic C (OC) by the wet oxidation method (Walkley and black 1934). Cation exchange capacity (CEC) was obtained through saturation with 1 M  $NH_4OAC$  at pH = 7 (Sumner and Miller 1996). Calcium carbonate ( $CaCO_3$ ) was determined by titration (Nelson 1982), and extractable Fe, Zn and Cu concentration with EDTA were determined by atomic absorption spectrometry (AAS) (Viro 1955).

**Table 1** Selected physicochemical properties of the studied soils

Soil	pH	EC <sub>e</sub> <sup>a</sup> (dsm <sup>-1</sup> )	CEC <sup>b</sup> (cmol kg <sup>-1</sup> )	OM <sup>c</sup> (%)	CaCO <sub>3</sub> <sup>d</sup> (%)	Clay (%)	Silt (%)	Sand (%)	Olsen-p (mg kg <sup>-1</sup> )	EDTA-extractable		
										Fe (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )	Cu (mg kg <sup>-1</sup> )
UF <sup>e</sup>	7.81	3.60	8.79	0.69	17.20	19.00	12.00	69.00	4.276	0.40	1.95	0.51
KF <sup>f</sup>	7.18	1.13	12.20	0.48	38.35	24.00	44.00	30.00	1.532	0.12	4.20	0.92

<sup>a</sup> Electrical conductivity, <sup>b</sup>cation exchange capacity, <sup>c</sup>organic matter, <sup>d</sup>calcium carbonate, <sup>e</sup>soil of Shahid Bahonar University farm, <sup>f</sup>Soil of Koohbanan farm region

**Table 2** Some chemical characteristics of organic matter used

Organic matter	pH	EC (dsm <sup>-1</sup> )	P (%)	Cu (mg kg <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )
Poultry manure (POM)	7.90	8.10	0.95	90.00	200.00
Pistachio compost (PIC)	8.25	7.24	0.12	1.00	8.50

**Organic matter characteristics**

The organic matters used in the study were poultry manure (M<sub>1</sub>) and pistachio compost (M<sub>2</sub>). Samples were air-dried and ground to pass through a 0.2-mm sieve, and analyzed for some chemical characteristics (Table 2). Soil pH was measured in 1–5 organic matters: water suspension, OC by the wet oxidation method (Walkley and black 1934), P by the vanadomolybdate phosphate method in a nitric acid system (Jackson 1967). EC was determined in 1–5, organic matters to water suspension by conductivity meter. Zn and Cu were determined by atomic adsorption spectrometry (Viro 1955).

**Treatments**

300 g of samples of each soil were placed in sets of the plastic containers. Mono potassium phosphate fertilizer, at rates of 0 (P<sub>0</sub>), and 100 (P<sub>100</sub>) parts per million of phosphorus, and air-dried poultry manure (M<sub>1</sub>) and pistachio compost (M<sub>2</sub>) at rates of 0 and 4% were mixed with the soils. The experimental design was CRD with two factor organic matters (OM) and P and each treatment was replicated three times.

**Incubation study**

The soils were incubated at 24–25°C and near field capacity for 90 days in the greenhouse. Soil samples were drawn after 90 days of incubation, dried, ground, and then used for studying the kinetics of P desorption. For P desorption studies, the soil samples were extracted by procedure using 0.5 M NaHCO<sub>3</sub> solutions. 1 g of each soil

was accurately transferred to 50 ml polythene tubes along with 20 ml of 0.5 M NaHCO<sub>3</sub> (pH: 8.5) solution. These samples were shaken for 11 different periods: 5, 10, 15, 30, 60, 120, 240, 480, 1,440, 2,880 and 4,320 min on an orbital shaker at 25°C. The supernatants were filtered by watman filter paper No. 42. The P concentration in the extract was determined by the ascorbic acid method (Watanabe and Olsen 1965).

The kinetics of P desorbed was evaluated using the zero order, first order, second order, third order, simple Elovich, power function, parabolic diffusion equation. Seven mathematical models used to describe the kinetic desorption of P are given in Table 3. The equation used to describe the kinetics of P desorption was evaluated according to its coefficient of determination (*r*<sup>2</sup>) and standard error of estimate (SE) (Chien and Clayton 1980). The standard error was calculated as follows:

$$SE = \left[ \frac{\sum (q - q')^2}{(n - 2)} \right]^{1/2}$$

where *q* and *q'* are the measured and predicted amounts of desorbed P at time *t*, respectively, and *n* is the number of measurements. Various Prate desorption parameters were subsequently obtained from fitted equations as follows: *a* and *b* from power function equation (Dang et al. 1994; McDowell and Sharpley 2003). The *α<sub>s</sub>* and *β<sub>s</sub>* from Elovich equation (Chien and Clayton 1980), and *k<sub>p</sub>* and *q<sub>o</sub>* from parabolic diffusion equation (Brar and Vig 1988; Toor and Bahl 1999).The various P rate desorption parameters were subsequently obtained from fitted equations.

**Statistical analysis**

All data were processed by Microsoft Excel 2003, and the regression of linear and other statistical analyses were conducted using the SPSS 11.5 software.

**Results and discussion**

Some chemical and physical properties of the studied soils are given in Table 1. Clay and CaCO<sub>3</sub> content ranged from 19 to 24% and from 17.2 to 38.35%, respectively. The soils

**Table 3** Equations tested to describe P desorption kinetic data (Dang et al. 1994)

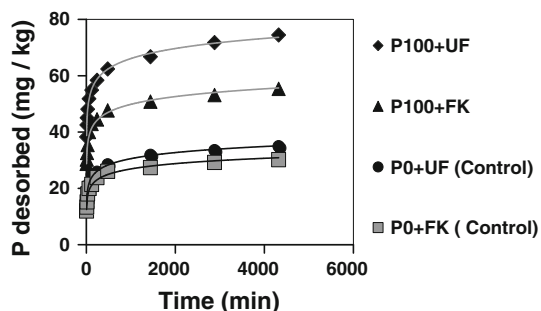
Model	Equation	Parameters
Zero order	$q_t = q_0 - k_0 t$	$k_0$ , zero order rate constant ( $\text{mg P kg}^{-1} \text{s}^{-1}$ )
First order	$\ln q_t = \ln q_0 - k_1 t$	$k_1$ , first-order rate constant ( $\text{s}^{-1}$ )
Second order	$1/q_t = 1/q_0 - k_2 t$	$k_2$ , second-order rate constant [ $(\text{mg P kg}^{-1})^{-1}$ ]
Third order	$t/q_t^2 = 1/q_0^2 - k_3 t$	$k_3$ , third-order rate constant [ $(\text{mg P kg}^{-1})^{-2} \text{s}^{-2}$ ]
Parabolic diffusion	$q_t = q_0 - k_p t^{1/2}$	$k_p$ , diffusion rate constant [ $(\text{mg P g}^{-1})^{-0.5}$ ]
Simple Elovich	$q_t = 1/\beta_s \ln(\alpha_s \beta_s) + (1/\beta_s) \ln t$	$\alpha_s$ , initial P desorption rate ( $\text{mg P kg}^{-1} \text{s}^{-1}$ ), $\beta_s$ , P desorption constant [ $(\text{mg P kg}^{-1})^{-1}$ ]
Power function	$q_t = at^b$	$a$ , initial P desorption rate constant ( $\text{mg P kg}^{-1} \text{s}^{-1}$ ) <sup>b</sup> ; $b$ , desorption rate coefficient [ $(\text{mg P kg}^{-1})^{-1}$ ]

$q_t$  ( $\text{mg P kg}^{-1}$ ) is the amount of P desorbed after  $t$  (s) period of extraction, and  $q_0$  ( $\text{mg P kg}^{-1}$ ) is that present at  $t = 0$  initially

were with pH 7.81 and 7.18, electrical conductivity ( $\text{EC}_c$ ) 3.60 and 1.13, Olsen-extractable phosphorus 4.276 and 1.532 and OM 0.69 and 0.48 and clay content 19.00 and 24%.

#### P fertilizer application on release of P

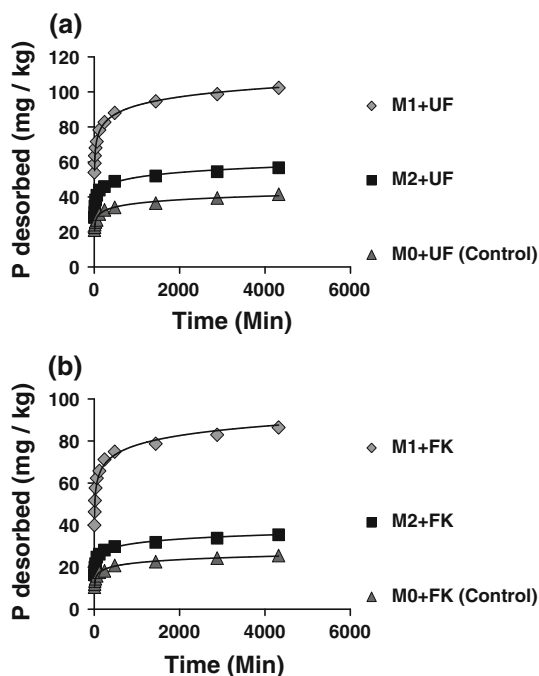
Release of P from the soils was rapid at first few hours and more slowly continued until an apparent equilibrium was approached. The amount of P was released at any time increases with the level of P fertilizer cumulative P desorption curves are presented in Fig. 1. In the control and treated soils with P fertilizer, there was a sharp initial increase in the desorbed P of the first time up to 240 min followed by a continued slow desorption up to 4,320 min. The gradual reduction in P release rate with time maybe a result of decreased surface charge and subsequent decrease in the interaction between the adsorbed phosphorus ions as desorption reaction progressed (Kuo and Lotse 1974). McDowell and Sharpley (2003) believed that P desorption and diffusion from inside of soil particles probably was the rate limiting steps in short- and long term P release reactions, respectively. De Smet et al. (1998) also related the initial fast and the final slow P release processes from non-calcareous soils to desorption and diffusion–dissolution reactions, respectively.



**Fig. 1** The cumulative desorbed of phosphorus as a function of time in the control and treated soils with  $100 \text{ mg P kg}^{-1}$

#### Organic matter and kinetics of P desorption

The data of the two soils showed an increase in the cumulative P desorbed with increasing shaking period with and without OM. Cumulative P desorption curves are presented in Fig. 2. In both the control and treated samples, there was a sharp initial increase in the desorbed P of the first time up to 240 min followed by a continued slow desorption up to 4,320 min. Elrashidi et al. (1975) suggested that there were two forms of P in highly calcareous soils: a quickly desorbed form and a slowly desorbed form, both of which were desorbed simultaneously during the initial 6–12 h. But after this period, only the slowly desorbed form occurred till 72 h when equilibrium was established. Shariatmadari et al. (2006) suggested that



**Fig. 2** The cumulative desorbed of phosphorus as a function of time in the treated soils with poultry manure ( $M_1$ ) and pistachio compost ( $M_2$ ) UF (a), KF (b)

mean rate of P desorption from soils at initial time ( $t = 0.25$  h) was about 300 times as much as the P desorption rate at final time ( $t = 72$  h). Toor and Bahl (1999) studied P desorption from manure-amended soils using 0.01 M  $\text{CaCl}_2$  solution. They reported that for cumulative desorbed P there were two reactions, the faster initial reaction which was followed by a slow secondary reaction. They observed that there was a initial faster reaction occurred up to 8 h, followed by a slow secondary reaction until 24 h.

This initial rapid P desorption was a characteristic of more labile P, while the latter fraction may be rated as less mobile, and this is known to be proportional to the number of phosphate-occupied sites (Kuo and Lotse 1973). Relatively higher surface coverage of soil with P and the easy replacement of the adsorbed phosphate ions may be attributed to a higher initial P desorption from the soil. The initial rapid desorption corresponded to the rapid dissolution of poorly crystalline or the amorphous phosphates in the soils, which were metastable and ultimately converted to crystalline forms such as octocalcium phosphate and hydroxyl apatite (Evans and Jurinak 1976; Griffin and Jurinak 1974). The slower second reaction may be attributed to the desorption of surface labile P and slow dissolution of the crystalline phosphate compounds in the soils (Toor and Bahl 1999). The desorption rate of phosphorus from soil can be attributed to several different processes. Three common P desorption mechanisms observed in the soils are the dissolution of various P minerals, the desorption of P from mineral surfaces, and the desorption of P from OM (mineralization). Desorption rates of P can vary depending on the mineral surface and sorption mechanisms. The dissolution rate of phosphorus minerals depends on the species, crystallinity, and the particle size of mineral (Hosseinpour and Biabanaki 2009).

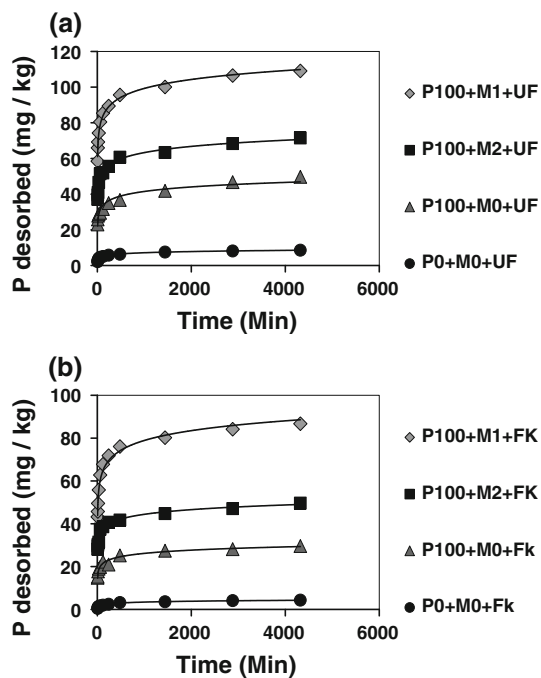
The results presented demonstrated that the pattern of P desorption was similar in the two soils but the content of P desorption in the rate of desorption in the UF soil was greater than that of the KF soil at all times (Fig. 1), because, the analysis of physicochemical properties of the studied soils demonstrated that the rate available phosphorus in UF soil was more than that the KF soil, and the rate of P concentration in the UF soil was about three times in KF soil. McDowell and Sharpley (2003), reported that the rate of desorption phosphorus increased with increasing Olsen P in the soils. The addition of OM ( $M_1$  and  $M_2$ ) increased P desorption in the soils along time more than control soils (Fig. 2). The P desorption rate was higher in the poultry manure-amended soils than that of the pistachio compost-treated soils. This was true at all incubation periods. This increase was significant at 0.05 levels. The reason that higher amounts of P were desorbed from the soil samples incubated with poultry manure is probably

the higher contribution of mineralized P by poultry manure. Microbial immobilization of P could have contributed to the lower amounts P desorbed from the samples incubated with pistachio compost. Sing and Jones (1976) also reported that higher amounts of P were desorbed from soil samples incubated with poultry manure followed by barley, beans, and alfalfa than with the control soil. The increase of P desorption in the amended soils may be attributed to the relatively high values of total P and OM in the sewage sludge (Hosseinpour and Pashamokhtari 2008). P desorption in fertilizer and poultry manure treatments was reported by Toor and Bahl (1999); they reported that OM helped in maintaining the crystalline products of phosphate and calcium phosphate in metastable or poorly crystalline forms through studying P desorption in fertilizer and poultry manure treatments. Also, OM increased the net negative surface charge and reduced the soil phosphate adsorption capacity (Jiao et al. 2007). On the other hand, OM may compete with P for sorption on the soil particle surfaces through blocking the adsorption sites and therefore may enhance the rate of P desorption (Shariatmadari et al. 2006). Organic compounds in the soils increased phosphorus availability through (1) formation of organophosphate complexes that are more easily assimilated by plants (2) anion replacement of  $\text{H}_2\text{PO}_4^-$  on adsorption places (3) coating of Fe/Al oxides by humus to form a protective cover and decreased P desorption, and (4) increasing the quantity of organic phosphorus mineralized to inorganic P (Havlin et al. 1991).

#### P fertilizer with organic matter application on release of P

The phosphorus release patterns of treated soils with both OM and P fertilizer are presented in Fig. 3. Application of OM and fertilizer P combined increased P recovery in each of the extraction time.

The same trends were observed for both soils. It was observed that P release from treated soils was initially rapid with a slow reaction continued. As is clear, in the each level of phosphorus fertilizer, application of OM increased release rate of phosphorus from the soils. In each of the extraction time can be separately observed that adding poultry manure ( $M_1$ ) and compost Pistachio ( $M_2$ ) in each level of fertilizer P, phosphorus was released greater from the soils than the control sample. It was observed the highest rate of P was released in the treatment combined poultry manure and 100 mg of fertilizer phosphorus levels. This result shows that application of OM increased the efficiency of fertilizer P, that this effect was greater in the poultry manure. Toor and Bahl (1997) and Halajnia et al. (2009) showed that the combined addition of poultry manure and fertilizer P had a synergistic effect and



**Fig. 3** Intrication of phosphorus and organic matter on the cumulative desorbed of phosphorus as a function of time UF (a), KF (b)

increased Olsen extractable P when compared with fertilizer P alone. Garg and Bahl (2008) reported that organic manure addition along with inorganic P, irrespective of the source, increased Olsen extractable P throughout the incubation period. Ohno et al. (2005) showed that application of animal manures may increase the bioavailability of soil P by increasing the concentration of soil dissolved organic C (DOC).

### Kinetic equation

The coefficients of determination ( $r^2$ ) and the standard errors of estimate (SE) for kinetic equations, which were tested to describe the P desorption data, are presented in Table 4. Results of the statistical analysis (data not shown) showed that, because of low  $r^2$  and high SE, zero-, first-, second- and third-order equations could not describe desorption of P. And because of the high coefficient of determination and low standard error of estimate in treated and untreated soils, measured data were best fitted using the power function law ( $r^2 = 0.94$  to  $0.98$  and  $SE = 0.04$  to  $0.08$ ), simple Elovich ( $r^2 = 0.96$  to  $0.99$  and  $SE = 0.03$  to  $0.06$ ), and parabolic diffusion law ( $r^2 = 0.75$  to  $0.95$  and  $SE = 0.06$  to  $0.20$ ) equations. The constants of these equations are shown in Table 5. These fitted equations have also successfully described the P desorption kinetics from soils by other researchers. McDowell and Sharpley (2003) studied the desorption kinetics as a function of soil test P concentration and indicated that power function equation could describe P desorption in the soils. Also, Shariatmadari et al. (2006) reported simple Elovich, power function law and parabolic diffusions as the best descriptive models for P desorption in some calcareous soils of selected arid and semiarid toposequences.

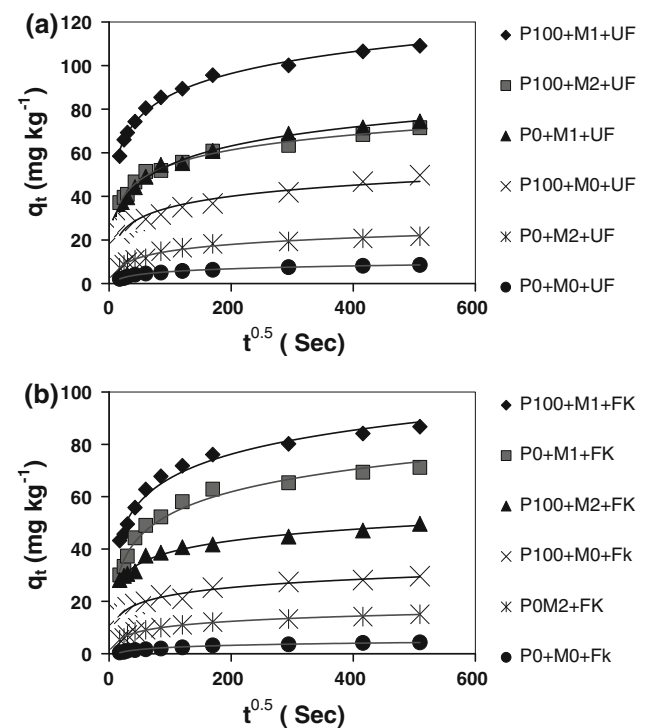
The parabolic diffusion equation:  $q_t = q_0 - k_p t^{0.5}$  was used for P desorption from the two soils (Fig. 4). Where,  $q_t$  is the quantity of the phosphorus desorbed in time  $t$ ,  $k_p$  is the diffusion rate constant (desorption rate factor) and  $q_0$  is the initial concentration of P in the soil solution (related to intensity parameter). The parameters for this equation are reported in Table 5. The values of  $k_p$  and  $q_0$  were generally

**Table 4** Coefficients of determination ( $r^2$ ) and standard errors of estimates (SE) for kinetic equations used to describe the P desorption data

Soils	Zero order		First order		Second order		Third order		Parabolic diffusion		Power function		Simple Elovich	
	$r^2$	SE	$r^2$	SE	$r^2$	SE	$r^2$	SE	$r^2$	SE	$r^2$	SE	$r^2$	SE
UF														
Control	0.64	0.12	0.53	0.31	0.41	0.41	0.30	1.91	0.85	0.12	0.96	0.07	0.99	0.03
M <sub>1</sub>	0.70	0.10	0.56	0.22	0.41	0.43	0.36	1.63	0.83	0.10	0.98	0.04	0.99	0.03
M <sub>2</sub>	0.68	0.11	0.57	0.26	0.46	0.42	0.36	1.65	0.95	0.06	0.96	0.06	0.99	0.04
P <sub>100</sub>	0.71	0.12	0.58	0.29	0.48	0.43	0.37	1.63	0.80	0.14	0.98	0.04	0.96	0.06
P <sub>100</sub> + M <sub>1</sub>	0.70	0.10	0.57	0.22	0.45	0.42	0.36	1.61	0.81	0.14	0.97	0.06	0.99	0.04
P <sub>100</sub> + M <sub>2</sub>	0.68	0.12	0.57	0.26	0.46	0.42	0.35	1.62	0.84	0.13	0.98	0.04	0.99	0.03
FK														
Control	0.68	0.11	0.56	0.27	0.44	0.41	0.36	1.64	0.88	0.11	0.96	0.06	0.98	0.04
M <sub>1</sub>	0.71	0.13	0.59	0.23	0.45	0.45	0.37	1.66	0.75	0.20	0.94	0.08	0.99	0.03
M <sub>2</sub>	0.68	0.12	0.57	0.26	0.46	0.42	0.35	1.62	0.83	0.14	0.96	0.05	0.99	0.03
P <sub>100</sub>	0.66	0.11	0.53	0.33	0.42	0.43	0.30	1.91	0.84	0.14	0.96	0.06	0.97	0.05
P <sub>100</sub> + M <sub>1</sub>	0.70	0.10	0.57	0.22	0.45	0.43	0.36	1.62	0.76	0.20	0.96	0.07	0.98	0.04
P <sub>100</sub> + M <sub>2</sub>	0.70	0.12	0.58	0.24	0.46	0.42	0.36	1.64	0.82	0.14	0.96	0.06	0.98	0.04

**Table 5** Rate parameters of kinetic models fitted on P desorption data in the studied soils

Soils	Parabolic diffusion		Power function		Simple Elovich	
	$q_0$	$k_p$	$a$	$b$	$\alpha_s$	$\beta_s$
<b>UF</b>						
Control	3.38	0.011	1.200	0.195	0.030	1.05
M <sub>1</sub>	40.79	0.078	17.29	0.120	3.890	0.160
M <sub>2</sub>	10.20	0.027	3.250	0.159	0.206	0.459
P <sub>100</sub>	26.30	0.050	12.80	0.105	5.210	0.274
P <sub>100</sub> + M <sub>1</sub>	70.68	0.089	38.09	0.087	112.5	0.138
P <sub>100</sub> + M <sub>2</sub>	43.24	0.063	22.10	0.095	25.85	0.199
<b>FK</b>						
Control	1.09	0.007	0.131	0.295	0.004	1.720
M <sub>1</sub>	40.26	0.074	16.19	0.125	3.450	0.162
M <sub>2</sub>	7.33	0.018	2.573	0.146	0.229	0.709
P <sub>100</sub>	17.41	0.028	8.499	0.101	5.950	0.459
P <sub>100</sub> + M <sub>1</sub>	53.06	0.079	25.03	0.104	16.91	0.151
P <sub>100</sub> + M <sub>2</sub>	31.84	0.039	17.64	0.083	69.81	0.317



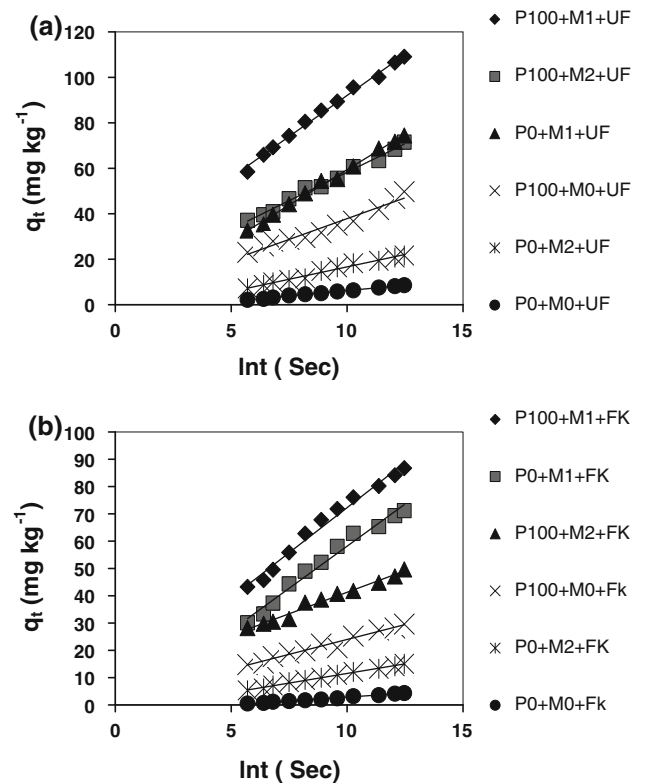
**Fig. 4** Kinetics of P desorption from UF (a) and KF (b) by NaHCO<sub>3</sub> during 4,320 min (259,200 s) as described by parabolic diffusion equation

higher in the combined treatment of M<sub>1</sub> and M<sub>2</sub> than that of the control treatment. Also, these parameters were highest in the soil samples incubated with M<sub>1</sub>. This difference was significant at 0.05 levels. Toor and Bahl (1999) suggested that the parabolic constants, diffusion rate ( $k_p$ ) and the

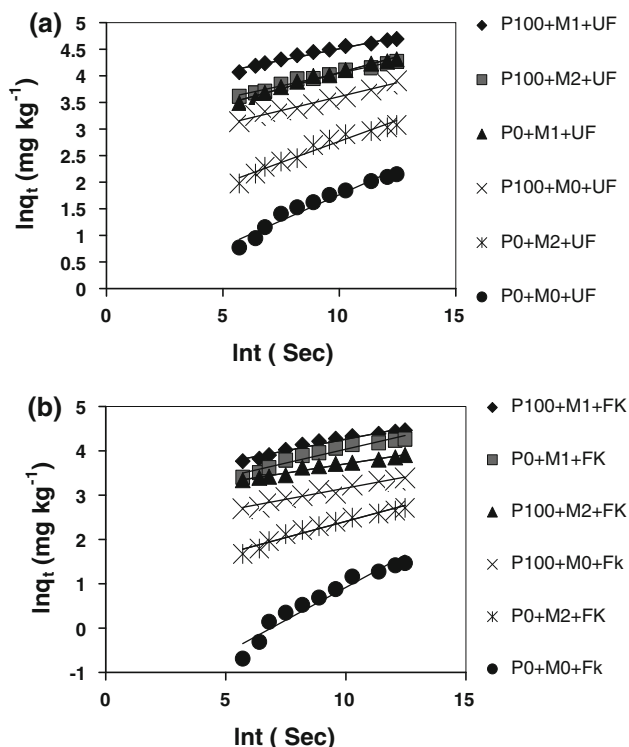
initial soil solution P concentration ( $q_0$ ) were generally higher in the combined treatment with M<sub>1</sub>.

The Elovich model in the linear form of  $q_t = 1/\beta_s$ . In  $\alpha_s \beta_s + 1/\beta_s \ln t$  (Simple Elovich equation) was tested by plotting the cumulative P desorbed as a function of the log of time, where,  $q_t$  is the concentration of P in the soil ( $\text{mg kg}^{-1}$ ) at any given time,  $t$  is the time (s) and  $\alpha_s$  and  $\beta_s$  are the desorption constants ( $\text{mg kg}^{-1}$ ). A linear relationship exists between ' $q_t$ ' and ' $\ln t$ ' for each of the treatments used in studied soils (Fig. 5). Simple Elovich equation parameters were determined from the slope and intercept of the linear plots. The constants of this equation are shown in Table 5. The Elovich constants, " $\alpha_s$ " increased and " $\beta_s$ " decreased with the application of poultry manure and pistachio compost in the studied soils. An increase in the value of " $\alpha_s$ " and a decrease in the value of " $\beta_s$ " is indicative of an increase in the rate of desorption (Chien and Clayton 1980).

The kinetic data of P desorption were used to test the suitability of the power function equation:  $q_t = a t^b$  or  $\ln q_t = \ln a + b \ln t$ , where,  $q_t$  is the quantity of the P desorbed in time  $t$ , and " $a$ " is the initial P desorption rate constant ( $\text{mg kg}^{-1}$ ), and " $b$ " is the desorption rate coefficient ( $\text{mg kg}^{-1}$ ). A linear relationship exists between ' $\ln q_t$ ' and ' $\ln t$ ' for each of the treatments used in the soils studied (Fig. 6). The constants of this equation are shown in



**Fig. 5** Kinetics of P desorption from UF (a) and KF (b) by NaHCO<sub>3</sub> during 4,320 min (259,200 s) as described by simple Elovich equation



**Fig. 6** Kinetics of P desorption from UF (a) and KF (b) by  $\text{NaHCO}_3$  during 4,320 min (259,200 s) as described by power function equation

Table 5. In comparison to the control soils, the value of “*a*” increased and the value of *b* decreased in the combined treatment with poultry manure and pistachio compost. An increase in the value of “*a*” constant and decrease in the value of “*b*” constant from power function rate equation probably indicates an increase in the rate of desorption from soils (Dang et al. 1994).

## Conclusion

This research shows that availability of P fertilizer in calcareous soils positively correlate with OM of soil. Interaction between P fertilizer rate and OM increase availability of P in soil. Application of OM increased the efficiency of fertilizer P, that this effect was greater in the poultry manure. Kinetics of soil phosphorus desorption in some treated OM agricultural soils in the east-southern Iran were assessed. The research results showed that, phosphorus release in the ShahidBahonar University research farm and Koohbanan farm in the control and in the OM amended soils were, at first, rapid and then became slower until equilibrium was reached. The faster initial reaction corresponded to the rapid dissolution of poor crystalline or amorphous phosphates, and the slower, second reaction was attributed to the desorption of surface labile P and slow dissolution of the

crystalline phosphate compounds in the soils. The results demonstrated that the patterns of P desorption were similar in the two soils but the content of P desorption in the UF soil was at all times, greater than that of the KF soil. As such, the results presented demonstrated that the kinetics of P desorption increases with Olsen-P concentration. Along time, the addition of OM ( $M_1$  and  $M_2$ ) increased the P desorption in the soils more than that the control soils. The P desorption rate was higher in the poultry manure-amended soils than that of the pistachio compost-treated soils. This may be attributed to the higher contribution of mineralized P by poultry manure. Seven kinetics equation models were tested to describe the phosphorus desorption in the soils. The kinetic data were best described by power function and simple Elovich equations as evidenced by the relatively higher values of determination coefficient ( $r^2$ ) and the relatively lower values of the standard error of estimate. Following these equations, parabolic diffusion equation was also well fitted the time-dependent P desorption data. Desorption rate constants of these equations indicated that the application of the OM can be effective on the rate of P desorption in the soil. Therefore, results from this study indicated that application of OM and fertilizer P combined increased P recovery in each of the extraction time, therefore, OM not only decreased phosphate retention of the soil but also increased phosphate desorption in the soil solution, This may thus lead to greater transport of phosphate from agricultural land to runoff.

**Acknowledgments** The authors wish to thank the Mahan international center of science high technology and environmental sciences for Excellences for financial and technical supports of this project.

## References

- Abrams MM, Jarrell WM (1995) Soil phosphorus as a potential non point source for elevated stream phosphorus levels. *J Environ Qual* 24:132–138
- Afif E, Matar A, Torrent J (1993) Availability of phosphate applied to calcareous soils of West Asia and North Africa. *Soil Sci Soc Am J* 57:756–760
- Amer F, Buldin DR, Black CA, Duke FR (1955) Characterization of soil phosphorus by anion exchange resin adsorption and  $\text{P}^{32}$  equilibration. *Plant Soil* 6:391–408
- Barrow NJ, Shaw TC (1975a) The slow reactions between soil and anions: 2 Effects of time and temperature on the decrease in phosphate concentration in the soil solution. *Soil Sci* 119(2):167–177
- Barrow NJ, Shaw TC (1975b) The slow reactions between soil and anions: 5. Effects of period of contact on the desorption of phosphate from soils. *Soil Sci* 119(4):311–320
- Bohn HL, Meneal BL, O'Connor GA (1985) *Soil chemistry*, 3rd edn. John Wiley & Sons, New York
- Brar BS, Vig AC (1988) Kinetics of phosphate release from soil and its uptake by wheat. *J Agric Sci* 110:505–513
- Chien SH, Clayton WR (1980) Application of Elovich equation to the kinetics of phosphate release and sorption in soils. *Soil Sci Soc Am J* 44:265–268



- Correll DL (1998) The role of phosphorus in the eutrophication of receiving water: a review. *J Environ Qual* 27:261–266
- Dang YP, Dala RC, Edwards DG, Tiller KG (1994) Kinetics of zinc desorption from vertisols. *Soil Sci Soc Am J* 58:1392–1399
- De Smet J, Vanderdeelen J, Hofman G (1998) Effect of soil properties on the kinetics of phosphate release. *Commun Soil Sci Plant Anal* 29:2135–2147
- Elkhatib EA, Hern JL (1988) Kinetics of phosphorus desorption from Appalachian soils. *Soil Sci* 145:222–229
- Elrashidi MA, Van Diest A, El-Damaty AH (1975) Phosphorus determination in highly calcareous soils by the use of an anion exchange resin. *Plant Soil* 42:273–286
- Evans RL, Jurinak JJ (1976) Kinetics of phosphate release from a desert soil. *Soil Sci* 121:205–211
- Garg S, Bahl GS (2008) Phosphorus availability to maize as influenced by organic manures and fertilizer P associated phosphatase activity in soils. *Bioresour Technol* 99:5773–5777
- Gee GW, Bauder JW (1986) Particle size analysis. In: Klute A (ed) *Methods of soil analysis, Part 1*, American Society of Agronomy, Madison, pp 383–411
- Griffin RA, Jurinak JJ (1974) Kinetics of the phosphate interaction with calcite. *Soil Sci Soc Am Proc* 38:75–79
- Halajnia A, Haghnia GH, Fotovat A, Khorasani R (2009) Phosphorus fractions in calcareous soils amended with P fertilizer and cattle manure. *Geoderma* 150:209–213
- Havlin JL, Beaton JD, Tisdale SL, Nelson WL (1991) *Soil fertility and Fertilizers: an introduction to nutrient management*, 7th edn. Prentice Hall of India Private Limited, New Delhi
- Hosseinpour AR, Biabanaki FS (2009) Impact of fertilizer phosphorus application on phosphorus release kinetics in some calcareous soils. *Environ Geol* 56:1065–1069
- Hosseinpour AR, Pashamokhtari H (2008) Impact of treated sewage sludge application on phosphorus release kinetics in some calcareous soils. *Environ Geol* 55:1015–1021
- Jackson ML (1967) *Soil chemical analysis*. Prentice Hall of India Private Limited, New Delhi
- Jiao Y, Joann K, Whalen H (2007) Phosphate sorption and release in a sandy-loam soil as influenced by fertilizer sources. *Soil Sci Soc Am J* 71:118–124
- Kuo S, Lotse EG (1973) Kinetics of phosphorus adsorption and desorption by hematite and gibbsite. *Soil Sci* 116:400–406
- Kuo S, Lotse EG (1974) Kinetics of phosphate adsorption and desorption by lake sediments. *Soil Sci Soc Am Proc* 38:50–54
- McDowell RW, Sharpley AN (2001) Approximating phosphorus release to surface runoff and subsurface drainage. *J Environ Qual* 30:508–520
- McDowell RW, Sharpley AN (2003) Phosphorus solubility and release kinetics as a function of soil test P concentration. *Geoderma* 112:143–154
- Mkhabela MS, Warman PR (2005) The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pug wash sand loam soil in Neva Scotia. *Agric Ecosyst Environ* 106:57–67
- Mohanty S, Paikaray NK, Rajan AR (2006) Availability and uptake phosphorus from organic manures in groundnut (*Arachis hypogea* L.) and corn (*Zea Mays* L.) sequence using radio tracer technique. *Geoderma* 133:225–230
- Nagarajah S, Posner AM, Quirk JP (1968) Desorption of phosphate from kaolinite by citrate and bicarbonate. *Soil Sci Soc Am Proc* 32:507–510
- Nelson RE (1982) Carbonate and gypsum. In: Page AL (ed) *Method of soil analysis, part 2*, 2nd edn. Agron. Monogr. 9. ASA and SSSA, Madison, pp 181–197
- Ohno T, Griffin TS, Liebman M, Porter GA (2005) Chemical characterization of soil phosphorus and organic matter in different cropping systems in Maine, USA. *Agric Ecosyst Environ* 105:625–634
- Olsen SR, Khasawneh FE (1980) Use and limitations of physical-chemical criteria for assessing the status of phosphorus in soils. In: Khasawneh FE et al (eds) *In the role of phosphorus in agriculture*, American Society of Agronomy, Madison, WI, pp 361–404
- Olsen SR, Cole CV, Watanabe ES, Dean LA (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA circular 939, USA Government Printing Office, Washington DC
- Pavlatou A, Polyzopoulos NA (1988) The role of diffusion in the kinetics of phosphate desorption: the relevance of the Elovich equation. *J Soil Sci* 36:425–436
- Raven KP, Hossner LR (1994) Soil phosphorus desorption kinetics and its relationship with plant growth. *Soil Sci Soc Am J* 58:416–423
- Reddy DD, Subba Rao A, Sammi Reddy K, Takkar PN (1999) Yield sustainability and phosphorus utilization in soybean-wheat system on Vertisols in response to integrated use of manure and fertilizer phosphorus. *Field Crops Res* 62:181–190
- Rhoades JD (1996) Salinity: electrical conductivity and total dissolved solids. In: Sparks DL (ed) *Methods of soil analysis. Part 3: chemical methods*. SSSA, Madison, pp 417–435
- Shariatmadari H, Shirvani M, Jafari A (2006) Phosphorus release kinetics and availability in calcareous soils of selected arid and semiarid toposequences. *Geoderma* 132:261–272
- Sharpley AN (1983) Effects of soil properties on the kinetics of phosphorus desorption. *Soil Sci Soc Am J* 47:462–467
- Sing BB, Jones JP (1976) Phosphorus sorption and desorption characteristics of soil as affected by organic residues. *Soil Sci Soc Am J* 40:389–394
- Skopp J (1986) Analysis of time-dependent chemical processes in soils. *J Environ Qual* 15:205–213
- Sumner ME, Miller WP (1996) Cation exchange capacity and exchange coefficients. In: Sparks DL (ed) *Methods of soil analysis. Part 3, chemical methods*. SSSA, Madison, pp 1201–1229
- Thomas GW (1996) Soil pH and soil acidity. In: Sparks DL (ed) *Methods of soil analysis. Part 3, chemical methods*. SSSA, Madison, pp 475–490
- Tisdale SL, Nelson WL, Beaton JD (1985) *Soil fertility and fertilizers*, 4th edn. Macmillan, New York
- Toor GS, Bahl GS (1997) Effect of solitary and integrated use of poultry manure and fertilizer phosphorus on the dynamics of P availability in different soils. *Bioresour Technol* 62:25–28
- Toor GS, Bahl GS (1999) Kinetics of phosphate desorption from different soils as influenced by application of poultry manure and fertilizer phosphorus and its uptake by soybean. *Bioresour Technol* 69:117–121
- Vig AC, Dev G (1979) Kinetics of phosphate desorption in soils. *J Nucl Agric Biol* 8:62–66
- Viro PJ (1955) Use of ethylenediaminetetraacetic acid in soil analysis. *I Exp Soil Sci* 79(6):459–465
- Walkley A, Black IA (1934) An examination of degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci* 37:29–37
- Watanabe FS, Olsen SR (1965) Test of an ascorbic acid method for determining phosphorus in water and NaHCO<sub>3</sub> extracts from soils. *Soil Sci Soc Am Proc* 29:677–678
- Xie LQ, Xie P, Tang HJ (2003) Enhancement of dissolved phosphorus release from sediment to lake water by Microcystis blooms an enclosure experiment in a hyper eutrophic, subtropical Chinese lake. *Environ Pollut* 122:391–399
- Yang JE, Skogley EO (1992) Diffusion kinetics of multinutrient accumulation by mixed-bed ion-exchange resin. *Soil Sci Soc Am J* 56:408–414