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MODELING OF SOIL AVAILABLE PHOSPHORUS BASED ON SOIL ORGANIC CARBON

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ABSTRACT

A well established regression model is a useful tool in development of prediction method of some soil physical or chemical properties, and can be used to investigate and analyze the soil. In soil studies, soil available phosphorous (AP) are often determined using laboratory tests, but it may be more suitable and economical to develop a method which uses some easily available soil properties. In this study, an exponential regression model for predicting soil AP from soil organic carbon (OC) was suggested and soil AP was estimated as a function of soil OC. The soil AP predicted from the soil AP-OC model was compared to the soil AP determined by laboratory test using the paired samples t-test and the Bland-Altman approach. The soil AP predicted by the soil AP-OC model was not significantly different from the soil AP determined by laboratory test ($P > 0.05$). The mean difference between the soil AP-OC model and laboratory test was 1.57 ppm (95% confidence interval: -2.88 and 6.03 ppm; $P = 0.453$). The standard deviation of the soil AP differences was 7.01 ppm. The statistical results of the study indicated that the soil AP-OC model provides an easy, economic and brief methodology to estimate soil AP and in order to predict soil AP based on soil OC the soil AP-OC model $AP = 0.7927\ e^{4.9922\ OC}$ with $R^2 = 0.92$ can be recommended.

Keywords: model, soil, phosphorus, organic carbon, prediction.

INTRODUCTION

In recent years, there has been increased interest in agricultural practices associated with the application phosphorus fertilizers. Phosphorus in plants performs unique function of energy transfer via formation of pyrophosphate bond. Phosphorus compounds (ADP and ATP) act as energy currency within the plants and involve in wide range of plant processes from permitting cell division to developing good root system (Meena *et al.* 2007). Phosphorus is removed from the soil by plant uptake or lost by soil erosion and runoff. Crops remove varying amounts of phosphorus from the soil (Manunta *et al.* 2001). Also, the availability of phosphorus in soils is often limited by fixation reactions, which convert the monophosphate ion into various insoluble forms (Di *et al.* 1994).

The importance of organic matter and accordingly organic carbon in the soil has been recognized for centuries as the key to soil fertility and productivity. Organic manures and other products of farming and related industries contribute to plant growth through their favorable effect on physical, chemical and biological properties of soil (Reddy *et al.* 2005; Meena *et al.* 2007). Besides, previously researches report that the availability of soil phosphorus is enhanced by adding organic matters, due to chelating of polyvalent cations by organic acids and other decay products (Jama *et al.* 1997; Reddy *et al.* 2005; Mohanty *et al.* 2006).

Precise information on the quantity of soil available phosphorus can be obtained only with the aid of almost laborious, costly and time consuming standard test methods (Bray and Kurtz 1945; Spratt *et al.* 1980). However, for almost 50 years many attempts have been made to predict some complex soil properties from some easily available soil properties using empirical models. In soil science, such empirical models are named pedotransfer functions (MacDonald 1998; Krogh *et al.* 2000).

So far many of the pedotransfer functions have been developed to predict various soil properties. MacDonald (1998) developed two models to predict soil cation exchange capacity (CEC) based on soil organic carbon (OC) and clay (CL) as $CEC = 2.0\ OC + 0.5\ CL$ and $CEC = 3.8\ OC + 0.5\ CL$ for Quebec and Alberta soil state in Canada, respectively. Rashidi and Seilsepour (2008) studied Varamin soils in Iran and proposed a model to predict soil CEC based on soil organic carbon (OC) and pH (PH) as $CEC = 26.76 + 8.06\ OC - 2.45\ PH$ with $R^2 = 0.77$. Seilsepour and Rashidi (2008a, b) also predicted soil CEC from organic carbon using a model as $CEC = 7.93 + 8.72\ OC$ with $R^2 = 0.74$. Moreover, the United States Salinity Laboratory (USSL) proposed one of the earlier model to predict soil exchangeable sodium percentage (ESP) from soil sodium adsorption ratio (SAR) as $ESP = -0.0126 + 0.01475\ SAR$ for United States soils (Richards 1954). Furthermore, Al-Busaidi and Cookson (2003) suggested a model to predict soil sodium adsorption ratio (SAR) based on soil electrical conductivity (EC) as $SAR = 0.464\ EC + 7.077$ with $R^2 = 0.83$ for saline soil in Oman.

Since, the above empirical models have been derived from different saline-zone soils, the general models between soil properties may be assumed to be similar to those. However, these models have been shown not to be constant, but to vary substantially with both solution ionic strength and the dominant clay mineral present in the soil (Shainberg *et al.* 1980; Nadler and Magaritz 1981; Marsi and Evangelou 1991; Evangelou and Marsi 2003). Therefore, the models are not constant and should be determined directly for the soil of interest.

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As previously researches report that there is a relationship between the availability of phosphorus in soil and soil organic matter (Jama *et al.* 1997; Reddy *et al.* 2005; Mohanty *et al.* 2006), soil organic carbon (OC) can be used to estimate soil available phosphorus (AP). Despite the considerable amount of research done, which shows the relationship between soil AP and soil OC, very limited work has been conducted to develop a soil AP-OC model. Therefore, the specific objective of this study was to develop a soil AP-OC model for calcareous soils of Varamin region in Iran, and to verify the developed model by comparing its results with those of the laboratory tests.

MATERIALS AND METHODS

Experimental procedure

Forty-eight soil samples were taken at random from different fields of experimental site of Varamin, Iran. The site is located at latitude of 35°-19'N and longitude of 51°-39'E and is 1000 m above mean sea level, in arid climate in the center of Iran. The soil of the experimental site was a fine, mixed, thermic, Typic Haplocambids clay-loam soil.

In order to obtain required parameters for determining soil AP-OC model, some physical and chemical properties of the soil samples i.e. sand, silt, clay (% by weight) and pH were measured using laboratory tests as described by the Soil Survey Staff (1996). The method of Walkley and Black (1934) by oxidation with potassium dichromate using the heating-block modification of Heanes (1984) was used to measure organic carbon (% by weight) of the soil samples. The method of Olsen and Sommers (1982) was used to measure available phosphorus of the soil samples. Physical and chemical properties of the forty-eight soil samples used to determine the soil AP-OC model are shown in Table-1.

Moreover, in order to verify the soil AP-OC model by comparing its results with those of the laboratory tests, twelve soil samples were taken at random from different fields of the experimental site. Sand, silt, clay (% by weight) and pH of the soil samples were measured using laboratory tests as described by the Soil Survey Staff (1996). Again, the method of Walkley and Black (1934) by oxidation with potassium dichromate using the heating-block modification of Heanes (1984) was used to measure organic carbon (% by weight) of the soil samples. The method of Olsen and Sommers (1982) was also used to measure available phosphorus of the soil samples. Physical and chemical properties of the twelve soil samples used to verify the soil AP-OC model are shown in Table-2.

Table-1. Mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of soil physical and chemical properties of 48 soil samples used to develop the soil AP-OC model.

Parameter	**Minimum**	**Maximum**	**Mean**	**S.D.**	**C.V.** (%)
Sand (%)	14.0	44.0	33.1	6.31	19.1
Silt (%)	30.0	56.0	45.3	4.13	9.12
Clay (%)	9.00	50.0	22.0	6.65	30.2
pH	7.00	8.10	7.50	0.27	3.60
Organic carbon (%)	0.24	0.71	0.54	0.14	25.5
Available phosphorus (ppm)	2.70	43.6	15.3	10.9	71.1

Table-2. Mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of soil physical and chemical properties of 12 soil samples used to verify the soil AP-OC model.

Parameter	**Minimum**	**Maximum**	**Mean**	**S.D.**	**C.V.** (%)
Sand (%)	10.0	34.0	24.1	5.87	24.4
Silt (%)	40.0	56.0	48.2	4.40	9.13
Clay (%)	18.0	50.0	28.2	7.90	28.0
pH	7.00	8.00	7.31	0.33	4.51
Organic carbon (%)	0.31	0.72	0.56	0.13	23.4
Available phosphorus (ppm)	4.40	49.3	17.3	13.7	78.9

Regression model

A typical exponential regression model is shown in Eq. (1):

$$Y = ae^{bX} \quad (1)$$

where

Y = Dependent variable, for example AP of soil

X = Independent variable, for example OC of soil

e = Base of the natural logarithm, 2.71828182845904

a, b = Regression coefficients

In order to predict soil AP from soil OC, an exponential regression model as Eq. (1) was suggested.

Statistical analysis

A paired samples t-test and the mean difference confidence interval approach were used to compare the soil AP values predicted using the soil AP-OC model with the soil AP values measured by laboratory tests. The Bland-Altman approach (1999) was also used to plot the agreement between the soil AP values measured by laboratory tests with the soil AP values predicted using the soil AP-OC model. The statistical analyses were performed using Microsoft Excel (Version 2003).

RESULTS

The p-value of the independent variable, Coefficient of Determination (R^2) and Coefficient of Variation (C.V.) of the soil AP-OC model is shown in Table-3. Based on the statistical result, the soil AP-OC model was judged acceptable. The R^2 value and C.V. of the soil AP-OC model were 0.92 and 23.8%, respectively. The soil AP-OC model is given in Eq. (2).

$$AP = 0.7927\ e^{4.9922OC} \quad (2)$$

DISCUSSIONS

A paired samples t-test and the mean difference confidence interval approach were used to compare the soil AP values predicted using the soil AP-OC model with the soil AP values measured by laboratory tests. The Bland-Altman approach (1999) was also used to plot the agreement between the soil AP values measured by laboratory tests with the soil AP values predicted using the soil AP-OC model.

The soil AP values predicted by the soil AP-OC model were compared with the soil AP values determined by laboratory tests and are shown in Table-4. A plot of the soil AP values determined by the soil AP-OC model and laboratory tests with the line of equality (1.0: 1.0) is shown in Figure-1. The mean soil AP difference between two methods was 1.57 ppm (95% confidence interval: -2.88 and 6.03 ppm; P = 0.453). The standard deviation of the soil AP differences was 7.01 ppm. The paired samples t-test results showed that the soil AP values predicted with the soil AP-OC model were not significantly different than the soil AP measured with laboratory tests (Table-5).

Table-3. The p-value of independent variable, Coefficient of Determination (R^2) and Coefficient of Variation (C.V.) of the soil AP-OC model.

Model	**Independent variable**	**p-value**	**R^2**	**C.V.** (%)
$AP = 0.7927\ e^{4.9922\ OC}$	OC	2.44E-26	0.92	19.6

Table-4. Chemical properties of soil samples used in evaluating the soil AP-OC model.

Sample No.	**Organic carbon** (%)	**Available phosphorus** (ppm)	
		Laboratory test	**Soil AP-OC model**
1	0.31	4.40	3.70
2	0.40	5.40	5.80
3	0.46	7.00	7.90
4	0.47	8.30	8.30
5	0.50	9.40	9.60
6	0.60	11.2	15.8
7	0.62	13.2	17.5
8	0.65	14.8	20.3
9	0.66	22.5	21.4
10	0.68	29.6	23.6
11	0.70	32.6	26.1
12	0.72	49.3	28.8

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Table-5. Paired samples t-test analyses on comparing soil AP determination methods.

Determination methods	**Average difference** (ppm)	**Standard deviation of difference** (ppm)	**p-value**	**95% confidence intervals for the difference in means** (ppm)
Laboratory test and soil AP-OC model	1.57	7.01	0.453	-2.88, 6.03

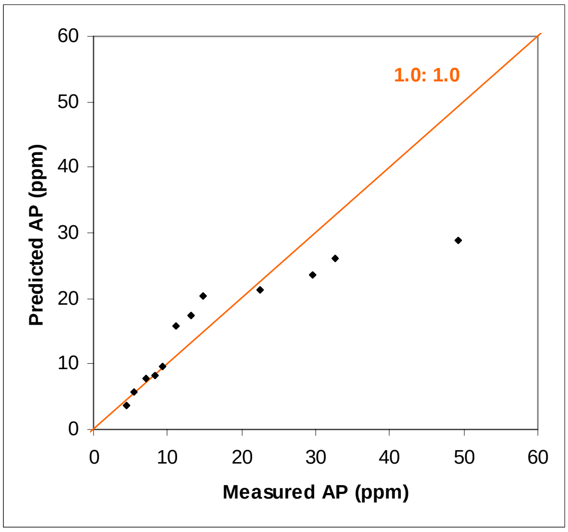

Figure-1. Measured AP and predicted AP using the soil AP-OC model with the line of equality (1.0: 1.0).

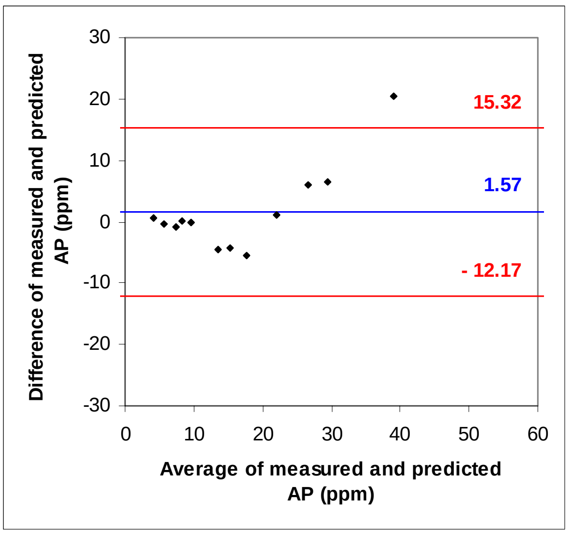

Figure-2. Bland-Altman plot for the comparison of measured AP and predicted AP using the soil AP-OC model; the outer lines indicate 95% limits of agreement (-12.17, 15.32) and the center line shows the average difference (1.57).

The soil AP differences between these two methods were normally distributed and 95% of the soil AP differences were expected to lie between $\mu+1.96\sigma$ and $\mu-1.96\sigma$, known as 95% limits of agreement (Bland and Altman, 1999). The 95% limits of agreement for comparison of soil AP determined with laboratory test and the soil AP-OC model were calculated at -12.17 and 15.32 ppm (Figure-2). Thus, soil AP predicted by the soil AP-OC model may be 12.17 ppm lower or 15.32 ppm higher than soil AP measured by laboratory test. Figure-2 also shows that for soil OC ranged from 0.30 to 0.60%, the soil AP predicted by the soil AP-OC model is almost equal to soil AP measured by laboratory test. As the soil OC increased, for soil OC ranged from 0.60 to 0.65% the soil AP-OC model overestimated the soil AP while for OC more than 0.65% the soil AP-OC model underestimated the soil AP. The average percentage differences for soil AP prediction using the soil AP-OC model and laboratory test was 19.6%.

CONCLUSIONS

An exponential regression model based on soil organic carbon (OC) was used to predict soil available phosphorus (AP) of calcareous soils of Varamin region in Iran. The soil AP values predicted using the soil AP-OC model was compared to the soil AP values measured by laboratory tests. The paired samples t-test results indicated that the difference between the soil AP values predicted by the soil AP-OC model were not significantly different from the soil AP values determined by laboratory test ($P > 0.05$). Therefore, the soil AP-OC model can provide an easy, economic and brief methodology to estimate soil AP.

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