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Determination of the best model for predicting soil available phosphorus based on soil organic carbon

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ABSTRACT

There are several methods for defining the determination of soil available phosphorous. Those methods require chemicals, devices, time, and hightcost. Consequently, pedotransfer functions more suitable and economical were used to predict the soil available phosphorous (AP) from soil organic carbon (OC).)Five models were utilized including exponential, linear, logarithmic, polynomial, and power models. Soil AP was predicted as a function of soil OC. The soil AP determined by laboratory tests was compared with the predicted soil AP based on the AP-soil OC model using the Bland-Altman method. The 95% limits of agreement for comparison of soil AP were determined with laboratory tests, and the soil AP pedotransfer function was computed at -1.707 and 1.542 mg kg $^{-1}$. The mean soil AP difference between the two methods was - 0.083 mg kg $^{-1}$. The polynomial model AP = 38.173 - 4.462 x OC+ 0.146 x OC^2 was given the best fit to predict soil available phosphorus, due to its high R^2 (0.868) and low RMSE (0.846).

تحديد أفضل نموذج للتنبؤ بالفوسفور الجاهز في التربة على أساس الكربون العض

سناء حمه غريب و كمال حمه كريم و رازان عمر علي
قسم الموارد الطبيعية ، كلية علوم الهندسة الزراعية ، جامعة السليمانية ، إقليم كوردستان – العراق

الخلاصة

هناك عدة طرق لتحديد الفوسفور الجاهز في التربة. تتطلب هذه االطرق العديد من المواد الكيميائية واستخدام أجهزة مختلفة ، ولتحديد الفسفور الجاهزللترب في المختبر أمر صعب ويستغرق وقتًا طويلاً ومكلفًا. وبالتالي امكانية استخدام دالة pedotransfer الأكثر ملاءمة واقتصادية للتنبؤ بالفوسفور الجاهز في التربة (AP) من خلال كمية الكربون العضوي في التربة (SOC). تم استخدام خمسة معادلات بما في ذلك المعادلةالخطية و الأسية واللوغاريتمية ومتعددة الحدود للتنبؤ بالفوسفور الجاهز للترب (AP) من خلال الكربون العضوي للتربة (SOC) . وتمت مقارنة AP المتوقعة مع AP للتربة التي تم تحديدها مختبرياً باستخدام طريقة Bland-Altman. كان متوسط فرق AP للتربة بين الطريقتين - 0.083 ملغم كغم $^{-1}$ عند حدود الاتفاق البالغة 95٪ لمقارنة AP للتربة المحددة مع الاختبار المختبري. تم حساب دالة AP Pedotransfer للتربة عند -1.707 و 1.542 ملغم كغم $^{-1}$. كان نموذج متعدد الحدود ($AP = 38.173 - 4.462 \times OC + 0.146 \times OC^2$) أعطى أفضل ملاءمة للتنبؤ بفوسفور الجاهز AP في التربة ، نظرًا لارتفاع (R^2 0.868) وانخفاض(RMSE 0.846).

الكلمات المفتاحية: نموذج متعدد الحدود ، التربة ، الفوسفورالجاهز ، دالة للتنبؤ، طريقة بلاند – ألتمان.

INTRODUCTION

A key macronutrient for plants that is important for growth and development is phosphorus. Natural phosphate content in the soil is depleted as a result of extensive vegetable and other crop cultivation, natural disasters, and other factors. Phosphate fertilizers have thus been applied to counteract this depletion and enhance the corresponding soil (Koralage et al., 2015). Organic amendments, particularly manure, lower soil sorption capacities and affinity constants for P. This may be a result of organic acids competing for P fixation sites or manure-derived components altering the appearance of exchangeable Al and Fe (Hue, et al. 1986; Iyamuremye, et al., 1996). The biochemical activities that change organic matter have a significant impact on the availability of P to crops in the short term, whereas geochemical processes typically define the status of P over the long term (Von Wandruszka, 2006). According to Acín-Carrera et al. (2013), soil organic carbon has a significant impact on agricultural output; as a result, soil organic carbon may serve as a useful indicator of soil health and quality for soil fertility and climate management (Beguera et al., 2015; Chen et al., 2017). One of them, soil organic matter, affects crop productivity by managing nutrient budgets in agricultural production systems. When there are few soil testing facilities, the soil organic matter content has a large spatial dependence, measuring it requires a lot of time and effort, and there are remote sensing-based spectral indices available, spatial estimation of the soil organic matter content is necessary (Mandal, 2016).

However, due to the large impact of soil texture on the concentration of OP, tree species had little to no impact on the C:OP (carbon: organic phosphorous) ratio in the mineral soil. In the organic layer, the dominant tree species only had an impact on the C: P ratio (Spohn, and Stendahl, 2022). In forests, grasslands, and croplands, phosphorus (P), which is necessary for all living things, frequently serves as a limiting factor for plant development and the production of biomass (Aerts and Chapin

2000; Trichet et al., 2009). Chemical techniques have historically been used to determine soil nutrients. This kind of technique is not only tedious and time-consuming but also destructive sampling, which makes it difficult to monitor the condition of the soil's nutrients in real-time and the field (Yu, et al., 2002). Dumenil (1961) demonstrated the relationship between N and P levels in maize leaves and maize production using a quadratic polynomial and its square root transformation. The overall definition of "pedotransfer function" (PTF) is the conversion of basic soil data into more relevant knowledge. It can also be described as the predictive capabilities of specific soil properties that are challenging to ascertain from other simple, frequent, or inexpensively measured values (Van Looy et al., 2017). It can be costly and time-consuming to measure the physical characteristics of soil, such as porosity and saturated hydraulic conductivity. Pedotransfer functions (PTFs) are used as predictors to estimate the physical features of soil using soil parameters that are plentiful, simple to measure, and affordable to eliminate time-consuming measurements (Perreault,2022). Both mechanistic and empirical approaches can be used to build PTFs, according to Patil and Singh (2016).

Mechanistic methods produce an analogous pore size distribution model from easily measurable soil parameters such as texture, bulk density, and particle density. The water content at various soil metric heads is then related to this model. Using common soil characteristics like pH, SOC, and soil texture in large forest soil inventories, it may be able to predict some Hedley P pools (Niederberger, 2019). It is common practice to quantify soil available phosphorus in laboratory tests for soil studies, but it would be more appropriate and cost-effective to build a pedotransfer function that makes use of several easily available soil characteristics. Seilsepour, et al. (2008) reported that the AP- OC soil model provides a simple, cost-effective, and short-term technique for calculating soil AP and predicting soil AP based on the soil OC of calcareous soils in the Varamin region of Iran using an exponential regression pedotransfer function ($AP = 0.793\ e^{4.992\ OC}$) with $R^2 = 0.920$. Seilsepour, et al. (2008) reported that the AP- OC soil model provides a simple, cost-effective, and short-term technique for calculating soil AP and predicting soil AP based on soil OC of calcareous soils in the Varamin region of Iran using an exponential regression pedotransfer function ($AP = 0.793\ e^{4.992\ OC}$) with $R^2 = 0.920$. In this study, soil organic carbon was used to estimate the amount of soil available phosphorus, and a pedotransfer function was proposed as a way to predict soil available phosphorous from soil organic carbon. In our region, there is no research concerning the prediction of soil available phosphorus depending on soil total organic carbon, the research is selected and its main objectives are to use the best models depending on soil organic carbon to predict the available phosphorus of studied soils, and to compare the results of the developed model with those of the laboratory tests will validate it.

MATERIALS AND METHODS

Soil databases have been taken from the Natural Resources Department, College of Agricultural Engineering Sciences, University of Sulaimani. One hundred and fifty soil samples with a depth (0 – 30 cm) were collected from different locations in the Kurdistan region of Iraq. This database consisted of data from 41 years (1979 -2020). Data used in this study belonged to some physiochemical characteristics of soil such as sand, silt, clay, soil organic carbon, and soil available phosphorous. Some of the physical and chemical properties of the soil studied include particle size distribution determined by sieving and pipette methods, and soil available phosphorous was determined by using the Olsen procedure according to the methods of soil, plant, and water analysis as outlined by (Estefan et al., 2013). Oxidizable organic matter was determined by the Walkley and Black, wet dichromate oxidation procedure as described by Nelson and Sommers, (1983). Additionally, by comparing their results with those of the laboratory studies, the soil available phosphorus -

soil total organic carbon model was confirmed. To test the soil available phosphorus-soil organic carbon model, fifty soil samples were randomly chosen from various locations. The physical and chemical properties of the fifty soil samples used to verify the soil AP - OC model are presented in (Table 1). Five mathematical models including Exponential, Linear, logarithmic, polynomial, and power models based on soil organic carbon to predict available phosphorus are suggested for study soils as shown in (Table 2). The model that gave the highest value of the determination coefficient (R^2) and the lowest value of root mean square error (RMSE) was considered as the best model equation. The determination coefficient and the root mean square error value were calculated according to the following equations:

$$1.\quad \mathrm{RMSE} = \frac{\sqrt{\sum_{i=0}^{n} (O_i - P_i)^2}}{n}$$

Where:

RMSE = root mean square error O_i = observed values P_i = predicted values

n = number of observations

$$2.\quad \mathrm{R}^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}$$

Where: R^2 = Determination coefficient y_i = observed value of y $\hat{y}$= predicted value of y

Table 1. The statistical results of soil physical and chemical properties of the fifty soil samples used to verify the soil AP - SOC model in the studied area

Parameters	Minimum	Maximum	Mean	S.D.	C.V. (%)
Sand g kg $^{-1}$	12.210	521.000	158.584	154.514	97.433
Silt g kg $^{-1}$	240.000	894.100	470.980	125.947	26.741
Clay g kg $^{-1}$	32.900	668.000	370.436	161.394	43.569
Soil organic carbon g kg $^{-1}$	8.469	17.343	12.712	2.519	19.820
Available P mg kg $^{-1}$	2.840	11.800	5.870	2.281	38.854

Table 2. Various models used in the studied soils.

Models	Equations	Parameters
Exponential	$\hat{Y} = a\ e^{b X}$	$\hat{Y}$ = Dependent variable (soil available phosphorous) X = Independent variable (soil organic carbon) e = Base of the natural logarithm, 2.718 a, b = Regression coefficients
Linear	$\hat{Y} = a + bX$	$\hat{Y}$ = Dependent variable (soil available phosphorous) X = Independent variable (soil organic carbon) a = intercept b = slope
Logarithmic	$\hat{Y} = a + b \ln (X)$	$\hat{Y}$ = Dependent variable (soil available phosphorous) X = Independent variable (soil organic carbon) Ln = Logarithms to the base e (called natural logarithms) a = intercept b = slope
Polynomial (Quadratic)	$\hat{Y} = a + b X + cX^2$	$\hat{Y}$ = Dependent variable (soil available phosphorous) X = Independent variable (soil organic carbon) a = intercept b , c = slope
Power	$\hat{Y} = a X^b$	$\hat{Y}$ = Dependent variable (soil available phosphorous) X = Independent variable (soil organic carbon) a, b = Regression coefficients

Statistical Analysis

Descriptive analyses such as average, minimum, maximum, standard deviation, and coefficient of variance were carried out using XLSTAT software program (Addinosoft, 2016). The agreement between the soil AP values determined by laboratory testing and the predicted soil available phosphorus values obtained from the soil available phosphorus - soil organic carbon model was also plotted using the Bland-Altman technique (1999).

RESULTS AND DISCUSSION

Five models depending on soil organic carbon (OC) were applied to predict soil available phosphorus (AP) in the investigated soils, including exponential, Linear, logarithmic, Polynomial, and Power. The model equation, that provided the highest value of determination coefficient (R^2) and the lowest value of root mean square error (RMSE) was considered the best model equation, due to its high R^2 (0.868) and low RMSE (0.846), therefore polynomial model (AP = 38.173 - 4.462 x OC+ 0.146 x OC^2) given the best fit to predict soil available phosphorus as shown in (Table 3), while Seilsepour et al, (2008)) showed that an exponential regression pedotransfer function (AP = 0.793 $e^{4.992\ OC}$) based on soil organic carbon was expressed as the most accurate model to predict soil phosphorus available of calcareous soils in the Varamin region of Iran. On the other hand, Niederberger (2019) suggests that, depending on extensive soil inventories, soil parameters like pH, soil organic carbon content, and soil texture may be utilized to predict specific soil Hedley P pools with different plant availability. Similarly, He, et al. (2021) showed that no variable could be utilized to predict the content of total phosphorus in soil. Instead, a combination of factors SOC, parent material, mean annual temperature, and soil sand content is required to accurately predict the total concentration of P in soil. Tuukkanen (2017) found that the complex hydrologic and biogeochemical interactions have an impact on the export of organic matter and nutrients from drained peatlands. Different soil and catchment features were related to variations in runoff's chemical oxygen demand total nitrogen, and total phosphorus concentrations using partial least squares regression.

Table 3. Root mean square error (RMSE) and determination coefficient (R^2) of five models were used to describe the prediction of available phosphorous based on soil organic carbon in studied soils.

Equation	RMSE	R^2
Exponential	1.027	0.804
Linear	1.274	0.694
logarithmic	1.126	0.761
Polynomial	0.846	0.868
Power	0.919	0.842

The Bland-Altman plot, also known as the difference plot (1999), is a graphical approach for comparing two measurement techniques that were used to plot the soil AP values measured from laboratory tests with the soil AP values predicted using the soil AP pedotransfer function. In order to compare the soil AP values measured in laboratory tests with those predicted by the soil AP pedotransfer function are presented in (Table 4). Plotting the soil AP values measured in laboratory testing and the soil AP pedotransfer function with the line of equality (1.0:1.0) as illustrated in (Fig.1). The soil AP pedotransfer function and the laboratory-based soil AP determination were compared, and the 95% limits of agreement were (-1.707 and +1.542 mg kg $^{-1}$). Between the two approaches, the average soil AP difference was (- 0.083 mg kg $^{-1}$) as shown in (Fig. 2). Thus, soil AP predicted by the soil AP pedotransfer function may be -1.707 mg kg $^{-1}$ lower or + 1.542 mg kg $^{-1}$ higher than soil AP determined by laboratory testing. Table 4 also illustrates that the soil OC ranged from 8.469 to 17.285 g kg $^{-1}$ for all fifty samples, and that, with the exception of sample 11, the soil AP predicted by the soil AP pedotransfer function is almost equal to the soil AP measured by laboratory test. This is confirmed by statistical analysis, which is shown in table (Table 4).

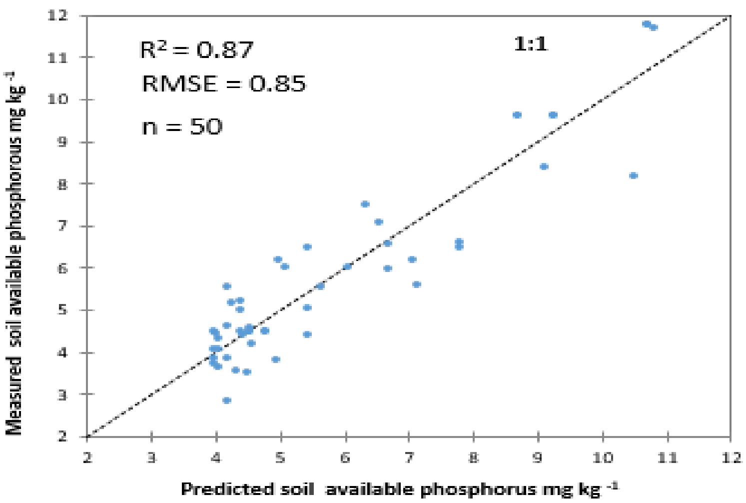

Figure 1. Measured soil available phosphorus and predicted soil available phosphorus using the soil available
Phosphorus – soil organic carbon model with the line of equality (1:1).

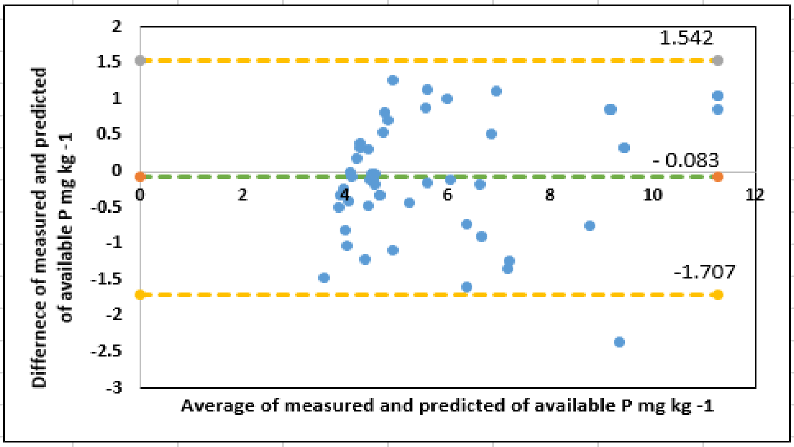

Figure-2. Bland-Altman plot for the comparison of measured AP and predicted AP using the soil AP-OC model; the outer lines indicate 95% limits of agreement (-1.707, + 1.542) and the center line shows the average difference (- 0.083)

Table 4. Chemical characteristics of the soil samples tested for the soil AP-OC model

Sample No.	Soil organic carbon (g kg $^{-1}$)	Available phosphorous mg kg $^{-1}$	
		Laboratory test (measured value)	Soil AP-OC model (predicted value)
1	14.965	3.850	4.096
2	12.587	6.020	5.141
3	12.181	4.390	5.484
4	15.371	3.750	4.083
5	14.153	3.860	4.267
6	14.559	4.330	4.158
7	13.805	3.580	4.399
8	11.021	5.990	6.731
9	12.181	5.040	5.484
10	17.343	4.220	4.703
11	16.531	2.840	4.310
12	12.181	6.490	5.484
13	16.531	4.610	4.310
14	12.993	4.510	4.846
15	13.532	4.420	4.528
16	12.761	3.800	5.008
17	11.949	5.540	5.702
18	11.543	6.000	6.121
19	14.675	3.640	4.135
20	8.643	8.160	10.515
21	11.311	7.500	6.382
22	10.731	6.200	7.104
23	11.137	7.100	6.589
24	13.921	5.170	4.351

Continue Table 4.

Sample No.	Soil organic carbon (g kg $^{-1}$)	Available phosphorous mg kg $^{-1}$	
		Laboratory test (measured value)	Soil AP-OC model (predicted value)
25	13.631	5.200	4.479
26	17.053	4.500	4.540
27	13.457	3.530	4.567
28	13.370	4.490	4.615
29	12.703	6.190	5.052
30	15.545	4.080	4.092
31	16.009	4.080	4.159
32	9.316	9.610	9.277
33	10.209	6.600	7.837
34	12.993	4.510	4.846
35	9.629	9.612	8.746
36	8.469	11.710	10.857
37	9.629	9.600	8.746
38	8.527	11.800	10.742
39	8.527	11.800	10.742
40	13.631	5.010	4.479
41	17.285	4.490	4.668
42	9.316	9.610	9.277
43	15.911	4.470	4.139
44	13.399	4.560	4.598
45	14.095	5.550	4.287
46	14.994	4.490	4.093
47	10.673	5.580	7.182
48	9.396	8.390	9.138
49	11.021	6.550	6.731
50	10.209	6.500	7.837

CONCLUSIONS

The polynomial model (AP = 38.173 - 4.462 x OC+ 0.146 x OC^2) is given as the best fit to predict soil available phosphorus due to its high R^2 (0.868) and low RMSE (0.846). Between the two approaches, the mean soil available phosphorus difference was - 0.083 mg kg $^{-1}$. Soil available phosphorous predicted by the soil-available phosphorous pedotransfer function may be -1.707 mg kg $^{-1}$ lower or +1.542 mg kg $^{-1}$ higher than soil available phosphorous determined by laboratory tests. Soil organic carbon ranged from 8.469 to 17.285 g kg $^{-1}$ for all fifty samples the soil available phosphorous predicted by the soil available phosphorous pedotransfer function is nearly equal to soil available phosphorous measured by laboratory test except sample eleven the soil available phosphorous pedotransfer function overestimated the soil available phosphorous.

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