

SOIL SCIENCE

Phosphorus Availability and Sorption Indices as Influenced by Some Properties of Calcareous Soils

M. S. Al-Sewailem

*Soil Science Department, College of Agriculture, King Saud University,
Riyadh, Saudi Arabia*

Abstract. Phosphorus availability in calcareous soils is low despite frequent P applications. There are various soil components that are affecting P sorption and availability. Two laboratory experiments were conducted on twenty-two calcareous soil samples varying in soil properties to investigate the relationships of various soil components with P availability and sorption. The P availability index (PAI), the increase in Olsen extractable soil P after equilibrating 50 mg P kg⁻¹ soil for 180 days, was significantly and negatively correlated with extractable Ca and Fe oxides ($r = -0.59$ and -0.48 respectively). The P sorption index (PSI), the amount of adsorbed P after adding 1500 mg P kg⁻¹ soil, was significantly and positively correlated with active CaCO₃ and total CaCO₃ contents ($r = 0.57$ and 0.53 respectively). No significant correlations were found between PAI and PSI with other soil components. In a stepwise regression procedure, the variance of PAI that was accounted for increased significantly from 37 to 73, and then to 85% by including extractable soil Ca, Fe oxides content, and soil pH. Likewise, the variance of PSI that was accounted for increased significantly from 23 to 34, 45, and then to 56% by including active CaCO₃ content, soil pH, organic matter content, and total P content. Further research is needed to incorporate measurements of soil components in calcareous soils with extractable P to give a better and more complete measure of P supply.

Introduction

The availability of phosphorus (P) to plants is very low in calcareous soils. This had been attributed to adsorption and/or precipitation reactions that occur between P and soil constituents [1, p. 263-310]. In calcareous soils, Olsen's extract [2] has been used over the years to account for P availability to plants and found to correlate significantly with plant yield and total uptake of P by plants [3]. However, several authors tried to relate various soil physical and chemical properties to P sorption and availability. Sharpley et al. [4] found that fertilizer P availability measured after 30 and 180 d of application decreased where the decrease positively related to calcium carbonate content of the calcareous soils. Chand *et al.* [5] reported that the available P significantly decreased

with an increase of soil pH and increased with an increase of organic carbon, cation exchange capacity (CEC) and clay. They found that these soil properties jointly contributed 37.5% variation in available P. In calcareous soils, Brar and Cox [6] indicated that P availability index (PAI) was negatively correlated with CEC and clay content at $\text{pH} < 8.8$, while in soils with $\text{pH} > 8.8$, soil pH was the dominant factor controlling the PAI. In a recent study on 19 calcareous soils from West Asia and North Africa, Afif *et al.* [7] found that PAI, at addition rate of $20\text{-}40 \text{ mg P kg}^{-1}$, was negatively correlated with Fe oxides content and CEC of the soils after 180 d. While at a rate of $300\text{-}500 \text{ mg P kg}^{-1}$, PAI was negatively correlated with CaCO_3 content but not correlated with Fe oxides regardless of the time.

A phosphate sorption index (PSI) for soils was proposed by Bache and Williams [8]. The PSI was calculated as $x/\log c$, where x = the amount of P adsorbed ($\text{mg}/100\text{g}$ soil), and c = equilibrium solution P concentration in mg P l^{-1} . This index was found to correlate strongly with the sorption maximum determined from Langmuir isotherm calculations. They indicated that PSI could be used as a suitable and rapid reference index to characterize the phosphate sorbing properties of soils. Brar and Cox [6] found that PSI was related to soil Ca and CaCO_3 content in their calcareous soils but the correlation coefficients were rather low.

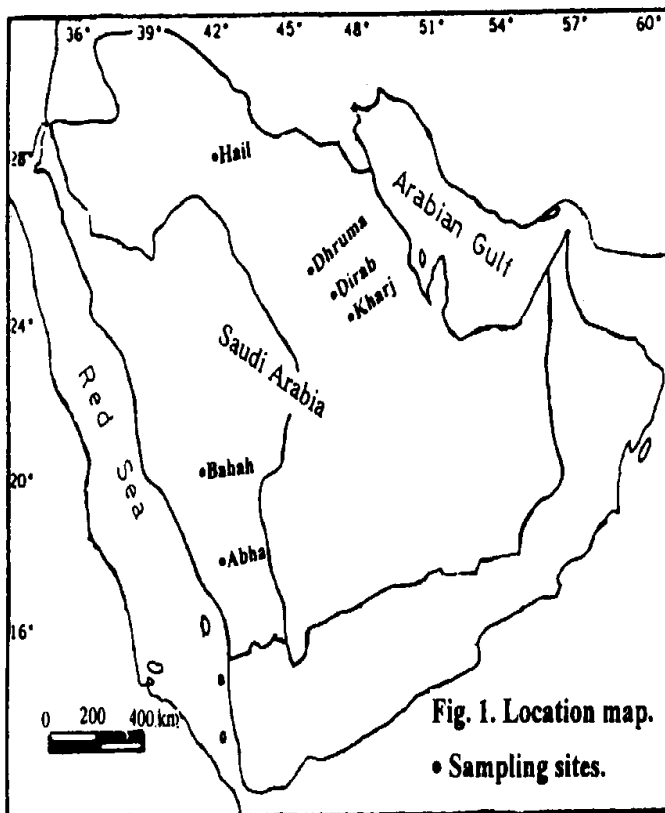
The purpose of the present study was to investigate the relationships between PAI and PSI, after P addition, as affected by some properties of calcareous soils in Saudi Arabia.

Material and Methods

Twenty-two surface soil samples (0-25 cm) were selected from the main agricultural areas of Saudi Arabia. Sampling sites are shown in the figure. These soils differed widely in their properties. The soil samples were air dried, gently crushed and passed through a 2-mm sieve, and analyzed for texture [9, p. 545-567], total calcium carbonate (CaCO_3) by the calcimeter method [10, p. 181-196], active CaCO_3 [11], cation exchange capacity (CEC) [12], neutral, molar ammonium acetate extractable Ca, soil Ca, [13, p. 89], free Fe oxides [14, p. 44], organic matter [15], total P [16, p. 403-430], and available soil P [2]. Dissolved P was analyzed by the ascorbic acid procedure of Watanabe and Olsen [17].

The PAI was estimated in a suspension of 1:1 soil : KH_2PO_4 solution to give a dose of 50 mg P/kg soil. The samples were equilibrated for 6 wks in open glass beakers at room temperature and rewetted with deionized water when approximately air dried. The PSI was determined by adding $1500 \text{ mg P kg}^{-1}$ to soil suspended in approximately 0.02M KCl solution in a soil : P solution ratio of 1:20 and shaking for 18 hr [8]. Samples

were duplicated and analyzed for Olsen extractable P [2]. Statistical analysis were done using SAS [18].



Results and Discussion

The range, mean, and standard deviation of several chemical and physical properties of the soils are presented in Table 1. The levels of available P in these soils were very low for most of the samples with an average of $4.74 \text{ mg P kg}^{-1}$ which is lower than the deficiency level of about 10 mg P kg^{-1} reported in calcareous soils from U.S.A and India [19–20]. The increase in available P (PAI), after addition of 50 mg P kg^{-1} , varied widely among soils ($0.95\text{-}37.75 \text{ mg P kg}^{-1}$). Table 2 shows the simple relationships between PAI and some soil properties.

Table 1. Range, mean and standard deviation (SD) of some soils properties used in this study

Soil properties	Range	Mean	SD
Clay (%)	9.00 - 30.00	15.86	5.50
Organic matter %	0.05 - 0.84	0.28	0.22
PH (soil paste)	6.52 - 8.14	7.64	0.42
CaCO ₃ (%)	2.75 - 56.00	21.16	15.84
CEC (cmol _c kg ⁻¹)	0.50 - 28.10	8.40	7.78
Soil Ca (cmol kg ⁻¹)	4.00 - 131.25	24.19	25.25
Olsen P (mg kg ⁻¹)	0.65 - 26.05	4.74	6.28
Total P (mg kg ⁻¹)	65.00 - 800.00	249.22	231.50
Fe oxides (%)	0.23 - 9.50	1.12	2.08
Active CaCO ₃ (%)	0.15 - 6.35	2.69	1.81
PAI (mg kg ⁻¹)	0.95 - 37.75	26.29	8.78
PSI	1.19 - 49.07	23.65	14.08

Table 2. Relationship between P availability index (PAI) and some soil properties

Soil properties	Correlation coefficient
Soil Ca (cmol kg ⁻¹)	- 0.59**
Fe oxides (%)	- 0.48*
CEC (cmol _c kg ⁻¹)	- 0.34
CaCO ₃ (%)	0.38
Organic matter (%)	0.01
pH	0.19
Active CaCO ₃ (%)	- 0.07

* and ** indicate significant at 0.05, 0.01 level respectively.

The data indicate that PAI was negatively and significantly correlated to soil Ca and free Fe oxides where the highest correlation coefficient value is found between PAI and soil Ca ($r = -0.59$) which in agreement with the finding of Brar and Cox [6]. In this regard, Fitter and Sutton [21] found that P adsorption was related to exchangeable Ca in soils with $pH > 5$. Also, Barrow *et al.* [22] measured P adsorption in 0.001M calcium chloride solutions and noticed sharp decreases in P concentration in equilibrium solutions as the pH was raised above 6 due to the precipitation of Ca-P as indicated by Shaviv and Shachar [23]. Recently, Carreira and Lajtha [24] found that P sorption markedly increased when Ca^{2+} was added to a 1:10 soil : solution mixture. In the present study soil Ca is considerably higher than the CEC, as given in Table 1, so the excess of Ca in the soil solution can easily react with soil phosphate. In stepwise regression analysis, the soil Ca content was able to explain 37% of the variation in PAI. The prediction equation was:

$$PAI = 31.62 - 0.21 \text{Soil Ca} \quad (1) \quad (P < 0.01)$$

The introduction of Fe oxides content together with soil Ca was able to explain 73% of the variation in PAI with the following prediction equation:

$$PAI = 35.50 - 0.24 \text{ Soil Ca} - 2.62 \text{ Fe oxides} \quad (2) \quad (P < 0.01)$$

Many studies have found that Fe oxides play an important role in P fixation of calcareous soils [6, 7, 25-27]. None of the other soil properties showed any significant relation with PAI (Table 2). Even though, soil pH was not related to PAI ($r = 0.19$), yet the inclusion of soil pH with soil Ca, and Fe oxides content further increased the predictability to 85% (Table 3). The prediction equation was:

$$PAI = -20.72 - 0.28 \text{ Soil Ca} - 2.57 \text{ Fe oxides} + 7.46 \text{ pH} \quad (3) \quad (P < 0.01)$$

In contrast to the findings of Sharpley *et al.* [4] the relationship between PAI and total $CaCO_3$ content of the soils in the present study (Table 2) was not significant which, in turn, is in agreement with that of Brar and Cox [6]. This contradictory results might be explained by the work of Afif *et al.* [7] who found that PAI was negatively correlated to $CaCO_3$ content of the soils at high P rates (500 mg P kg^{-1}). While at low P rates ($20 - 40 \text{ mg P kg}^{-1}$), it was negatively correlated only to Fe oxides and CEC of the soils. They suggested the dominance of the precipitation of Ca-P at the high P rates and the adsorption processes mainly occurring at the low rates. The positive trend between PAI and $CaCO_3$ content in the present study might be due to the selectivity of Olsen solution to extract P initially bounded to $CaCO_3$. Khaled and Al-Sewailam [28] found positive correlation between available P as extracted by Olsen solution and Ca-P which has high significant positive correlation with $CaCO_3$ content of calcareous soils.

Table 3. Stepwise multiple regression equations indicating partial contribution of different soil properties to PAI

Dependent variable	Equations	R ²
PAI	PAI = 31.62 - 0.21 Soil Ca	0.37
	PAI = 35.50 - 0.24 Soil Ca - 2.62 Fe oxides	0.73
	PAI = -20.72 - 0.28 Soil Ca - 2.57 Fe oxides	0.85
	+ 7.46 pH	

The P sorption index (PSI) for these soils are given in Table 1. It ranged from 1.19 to 49.07 with a mean of 23.65±14.08. Table 4 shows the simple correlation coefficient between PSI and some soil properties. The data indicate that PSI was significantly correlated with active and total CaCO₃ contents ($r = 0.57$ and $r = 0.53$ respectively). Similar results with CaCO₃ content were found by Brar and Cox [6] and Sharpley *et al.* [4] except that Brar and Cox [6] found significant correlation between PSI and soil Ca while it was not in our study ($r = 0.38$). None of the other soil properties showed any significant relation with PSI. In stepwise regression analysis, the active CaCO₃ content was able to explain 23% of the variation in PSI (Table 5). The prediction equation was:

$$\text{PSI} = 15.23 + 3.86 \text{ active CaCO}_3 \quad (4) \quad (P < 0.01)$$

When the soil pH was included to active CaCO₃ content the predictability increased significantly ($P < 0.05$) from 23% to 34% (Table 5) and to 45% by including organic matter, and to 56% by including total phosphorus in soils according to the equation:

$$\text{PSI} = -143.31 + 17.75 \text{ pH} + 6.93 \text{ active CaCO}_3 + 32.37 \text{ O.matter} + 0.02 \text{ Total P} \quad (5) \quad (P < 0.05)$$

Table 4. Relationship between P sorption index (PSI) and some soil properties

Soil properties	Correlation coefficient
Active CaCO ₃ (%)	0.57**
CaCO ₃ (%)	0.53**
Soil Ca (cmol kg ⁻¹)	0.38
pH	0.37
Fe oxides (%)	-0.33
CEC (cmol _c kg ⁻¹)	-0.19
Organic matter (%)	-0.16

* and ** indicate significant at 0.05, 0.01 level respectively.

Calcium carbonate has two important roles in its effect on P reactions in soils, one as a P adsorbent and the other in its effect on other soil properties such as pH and Ca concentration [29]. It is noteworthy that both total and active CaCO₃ contents had significant correlation with PSI but not correlated to PAI. This effect might be due to the larger amount of P (1500 mg P kg⁻¹ soil) used in the PSI in comparison with the lower amounts of P (50 mg P/kg soil) used in the PAI experiment. Also, the lack of correlation between Fe oxides and PSI support the suggested idea that precipitation is the dominant mechanism for P fixation at high P addition rates.

Table 5. Stepwise multiple regression equations indicating partial contribution of different soil properties to PSI

Dependent variable	Equations	R ²
PSI	PSI = 15.23 + 3.86 active CaCO ₃	0.23
	PSI = -55.49 + 9.37 pH + 3.53 active CaCO ₃	0.34
	PSI = -103.20 + 13.95 pH + 5.48 active CaCO ₃ + 26.44 O. matter	0.45
	PSI = -143.31 + 17.75 pH + 6.93 active CaCO ₃ + 32.37 O. matter + 0.02 Total P	0.56

References

- [1] Sample, F.C. Soper, R.J. and Racz, G.J. "Reaction of Phosphate Fertilizers in Soils." In: *The Role of Phosphorus in Agriculture*. Khasawneh, F.E. et al. (Eds.), Am. Soc. Agronomy, Crop Sci. Soc. Am. and Soil Sci. Soc. Am., Madison, WI., 1980
- [2] Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. "Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate." USDA. Circ. No. 939. U.S. Gov. Print. Office, Washington, DC., 1954.
- [3] Rahmatullah, Gill, M.G., Shaikh, B.Z. and Salim, M. "Bioavailability and Distribution of Phosphorus Among Inorganic Fractions in Calcareous Soils." *Arid Soil Res. Rehabilitation.*, 8 (1994), 227-234.
- [4] Sharpley, A.N. Singh, U. Uehara, G. and Kimble, J. "Modeling Soil and Plant Phosphorus Dynamics in Calcareous and Highly Weathered Soils." *Soil Sci. Soc. Am. J.*, 53 (1989), 153-158.
- [5] Chand, Tek., Tomar, N.K. and Singh, J.P. "Effect of Soil Properties on the Forms of Inorganic Phosphorus in Alkaline-calcareous Soils of Different Agroclimatic Zones." *Arid Soil Research and Rehabilitation*, 5 (1991), 199-210.
- [6] Brar, S.P.S. and Cox, F.R. "Phosphorus Sorption and Availability Indices as Affected by Properties of Calcareous Soils." *Commun. Soil Sci. Plant Anal.*, 22 (1991), 1225-1241.
- [7] Arif, E., Matar, A. and Torrent, J. "Availability of Phosphate Applied to Calcareous Soils of West Asia and North Africa." *Soil Sci. Soc. Am. J.*, 57 (1993), 756-760.
- [8] Bache, B.W. and Williams, E.G. "A Phosphate Sorption Index for Soils." *J. Soil Sci.*, 22 (1971), 289-301.
- [9] Day, P.R. "Particle Fractionation and Particle-size Analysis." In: Black, C.A. (Ed.). *Methods of Soil Analysis*. Part 1. Am. Soc. Agronomy and Soil Sci. Soc. Am., Madison, WI., 1965.
- [10] Nelson, R.E. "Carbonate and Gypsum." In: Page, A.L. et al. (Eds.) *Methods of Soil Analysis*. Part 2. *Chemical and Microbiological Properties*. 2nd ed. Am. Soc. Agronomy and Soil Sci. Soc. Am., Madison, WI., 1982.
- [11] Drouineau, G. "Dosage Rapide du Calcaire Actif du sol: Nouvelles donnees sur la repartition et la nature des fractions calcaires." *Ann. Agron.*, 12 (1942), 441-450.
- [12] Polemio, M. and Roades, J.D. "Determining Cation Exchange Capacity. A New Procedure for Calcareous and Gypsiferous Soils." *Soil Sci. Soc. Am. J.* 41 (1977), 524-528.
- [13] Jackson, M.L. *Soil Chemical Analysis*. New Delhi: Prentice-Hall, Inc., 1973.
- [14] Jackson, M.L. *Soil Chemical Analysis-Advanced Course*. 2nd ed. Published by the author. Univ. of Wisconsin. Madison, USA., 1975.
- [15] Walkley, A. and Black, I.A. "An Examination of the Digestion Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method." *Soil Sci.*, 37 (1934), 29-38.

- [16] Olsen, S.R. and Sommers, L.E. "Phosphorus." In: Page, A.L. et al. (Eds.) *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. 2nd ed. Am. Soc. Agronomy and Soil Sci. Soc. Am. Madison, WI., 1982.
- [17] Watanabe, F.S. and Olsen, S.R. "Test of Ascorbic Acid Method for Determining Phosphorus in Water and NaHCO₃ Extracts from Soil." *Soil Sci. Soc. Am. Proc.*, 29 (1965), 677-678.
- [18] SAS. *User's Guide Statistical Analysis System*. Cary, NC: SAS Institute Inc., 1986.
- [19] Bowman, R.A., Olsen, S.R. and Watanabe, F.S. "Greenhouse Evaluation of Residual Phosphorus by Four Phosphorus Methods in Neutral and Calcareous Soils." *Soil Sci. Soc. Am. Proc.*, 42 (1978), 451-454.
- [20] Gattani, P.D. and Seth, S.P. "Phosphorus Soil Test Correlation Studies in Rajasthan." *J. Ind. Soc. Soil Sci.*, 21 (1973), 373-375.
- [21] Fitter, A.H. and Sutton, C.D. "The Use of Freundlich Isotherm for Soil Phosphate Adsorption Data." *J. Soil Sci.*, 26 (1975), 241-246.
- [22] Barrow, N.J., Bowden, J.W., Posner, A.M. and Quirk, J.P. "Describing the Effects of Electrolyte on Adsorption of Phosphate by a Variable Charge Surface." *Aust. J. Soil Sci.*, 18 (1980), 395-404.
- [23] Shaviv, A. and Shachar, N. "A Kinetic-mechanistic Model of Phosphorus Sorption in Calcareous Soils." *Soil Sci.*, 148 (1989), 172-178.
- [24] Carreira, J.A. and Lajtha, K. "Factors Affecting Phosphate Sorption along a Mediterranean, Dolomitic Soil and Vegetation Chronosequence." *European J. Soil Sci.*, 48 (1997), 139-149.
- [25] Holford, I.C.R. and Mattingly, G.E.G. "The High- and Low-energy Phosphate Adsorbing Surfaces in Calcareous Soils." *J. Soil Sci.*, 26 (1975), 407-417.
- [26] Ryan, J., Curtin, D. and Cheema, M.A.. "Significance of Iron Oxides and Calcium Carbonate Particle Size in Phosphorus Sorption by Calcareous Soils." *Soil Sci. Soc. Am. J.*, 48 (1984), 74-76.
- [27] Borrero, C., Pena, F. and Torrent, J. "Phosphorus Sorption by Calcium Carbonate in Some Soils of the Mediterranean Part of Spain." *Geoderma*, 42 (1988), 261-269.
- [28] Khaled, E.M. and Al-Sewailem, M.S. "Phosphate Forms as Affected by Different Soil Properties in Some Soils of Saudi Arabia." *Annals Agric. Sci., Ain Shams Univ., Cairo.*, 41 (1996), 1075-1084.
- [29] Holford, I.C.R., Chater, M. and Mattingly, G. "Effects of Decalcification on the Phosphate Sorption Characteristics of Eight Calcareous Soils." *Aust. J. Soil Res.*, 28 (1990), 919-928.

أدلة جاهزية ومسك الفوسفور وتأثيرها ببعض خواص الترب الجيرية

محمد بن سليمان السويلم

قسم علوم التربة - كلية الزراعة - جامعة الملك سعود بالرياض

المملكة العربية السعودية

ملخص البحث. جاهزية الفوسفور في الترب الجيرية منخفضة بالرغم من إضافات الفوسفور المتكررة . يوجد عدد من مكونات التربة التي تؤثر على مسك وجاهزية الفوسفور ، ولقد أجريت تجربتان معملتان على ٢٢ عينة من الترب الجيرية المختلفة في خواصها لإيجاد العلاقات بين عدد من خواص التربة مع كل من جاهزية الفوسفور ومسكه. أوضحت نتائج التحليل الإحصائي وجود علاقة معنوية سالبة بين دليل جاهزية الفوسفور (والذي يمثل الزيادة في كمية الفوسفور المستخلص بمحلول اولسن بعد معادلة ٥٠ ملجم / كجم تربة لمدة ١٨٠ يوماً) وكل من الكالسيوم المستخلص ($r = -0.59$) وأكاسيد الحديد ($r = -0.48$). كذلك دليل مسك الفوسفور (والذي يمثل كمية الفوسفور المسوك بعد إضافة ١٥٠٠ ملجم/كجم تربة) كون علاقة معنوية موجبة مع كمية كربونات الكالسيوم النشطة ($r = 0.57$) وكمية كربونات الكالسيوم الكلية ($r = 0.53$). وهذا ولم توجد علاقات معنوية بين خواص التربة الأخرى المدروسة مع دليل جاهزية الفوسفور أو دليل مسك الفوسفور .

أوضحت دراسات الإندثار المتعدد المرحلي بأن الاختلافات المحسوبة في دليل جاهزية الفوسفور قد زادت معنويا من ٣٧ إلى ٧٣ ومن ثم إلى ٨٥٪ بعد إدخال الكالسيوم المستخلص ، أكاسيد الحديد ، والرقم الهيدروجيني للتربة في معادلة الإندثار . كذلك الاختلافات المحسوبة في دليل مسك الفوسفور قد زادت معنويا من ٢٣ إلى ٣٤ ، ٤٥ ، ومن ثم إلى ٥٦٪ بعد إدخال كربونات الكالسيوم النشطة ، الرقم الهيدروجيني للتربة ، المادة العضوية ، الكمية الكلية للفوسفور في معادلة الإندثار. هناك حاجة إلى إجراء مزيد من البحوث لإدخال نتائج تحليل مكونات التربة الجيرية مع الفوسفور المستخلص وذلك لإعطاء صورة واضحة وكاملة للقدرة الإمدادية للفوسفور.