

Evaluation of Phosphorus Extraction Methods for Assessing Phosphorus Availability of Some Sri Lankan Soils

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ABSTRACT. Available P status of twenty acidic soils (pH 4.50-6.83) was determined by extracting with five different extractants, namely, Olsen, Bray-1, Bray-2, Calcium lactate (CAL) and De-ionized water. Suitability of these extractants in relation to soil chemical properties, mainly soil pH and P buffer capacity, was studied considering the relationship between P quantity extracted and P uptake by an indicator plant under greenhouse conditions over 120 days. To obtain information on P buffer capacity an adsorption experiment was conducted. Adsorption data were fitted to two surface Langmuir isotherm, and maximum buffer capacity (MBC) values were calculated. P quantities extracted by all extractants significantly correlated with cumulative P uptake. The highest correlation was observed with Bray-2 extractant ($r = 0.76^{**}$) and the lowest was observed with Olsen ($r = 0.67^*$). When soils with pH greater than 5.0 were considered separately, the relationship between P extracted and P uptake values improved for all five methods, and for these soils, CAL method was the most suitable. None of the methods were appropriate to assess P availability of soils with pH less than 5.0.

Based on MBC values, soils were grouped into high and low P retention categories. According to regression analysis, Bray-2, CAL and De-ionized water methods were more suitable for estimating P availability in soils with low P retention. None of the methods except Olsen method seems to be suitable to assess P availability in soils with high P retention. Bray-2 method was the most suitable extractant to assess P availability in soils with a wide range of chemical properties.

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INTRODUCTION

Assessment of available P in soils is complicated and often unsatisfactory. This is mainly because available P content of soils is regulated by many factors, such as P concentration in soil solution (intensity), the amount of solid phase P (quantity) and diffusion of P in soils (Gunary and Sutton, 1967). Therefore, in assessing available P status of soils one should consider the relationships among intensity, quantity and diffusion as well as factors influencing these components such as pH and P buffer capacity (Kamprath and Watson, 1980).

During the last few decades several chemical extraction methods have been proposed and tested to evaluate P availability of soils. These methods vary mainly on pH of the extractant, nature and concentration of cations and anions, temperature, period of extraction and soil: extractant ratio (Williams and Knight, 1963). However, most of these methods were unsuccessful in assessing P availability, specially when soils with varying characteristics were compared (Mengel, 1985). Thus, selecting an appropriate method to assess available P status is not a simple exercise.

This study, therefore, was conducted with the objective of investigating the suitability of five different extractants in assessing soil available P status, considering soil pH values and P buffer capacity.

MATERIALS AND METHODS

Soil samples were collected to a depth of 15 cm from 20 different locations in Sri Lanka, representing Reddish brown earths (RhodustalFs), Non-calcic brown soils (HaplustalFs), Reddish brown latosolic soils (Rhodudults), Immature brown loams (Dystropepts), Red yellow podzolic soils (Tropudults) and Regosols (Quartzipsamments). Soils were air-dried and sieved to pass through a 2 mm sieve, prior to laboratory and greenhouse studies.

Greenhouse experiment

A pot experiment was conducted in a greenhouse to assess the P availability, using rice (*Oryza sativa*) variety H-4 as the indicator plant with 4 kg soil per pot. All soils were replicated four times. The soil moisture status was maintained approximately at 70 % of field capacity throughout

the experiment. N and K were added at the rate of 0.2 g per pot, as NH_4NO_3 and K_2SO_4 respectively. Five days after application of fertilizer 10 seeds were dribbled per pot. Initial soil sampling was done at the time of seeding. P status of soils was evaluated by Olsen, Bray-1, Bray-2, Calcium lactate (CAL) and de-ionized water extraction methods (Table 1). Within the total experimental period of 120 days, above ground parts of rice plants were harvested and pots were re-seeded four times at every 30 days. Samples were oven-dried and analyzed for phosphorus, according to the method of Chapman and Pratt (1961). Using these data, cumulative phosphorus uptake values were calculated. Simple linear regression was used to establish the relationship between plant P uptake and the quantity of P extracted by the different extraction methods.

Table 1. Details of methods used for determining available P.

Method	Extracting solution	Shaking Time(min)	Soil extract ratio	Reference
Olsen	0.5M NaHCO_3 at pH 8.5	30	1:20	Olsen <i>et al.</i> , (1954)
Bray-1 +0.025M HCl	0.03M NH_4F	1	1:10 (1945)	Bray & Kurtz
Bray-2	0.03M NH_4F 0.1M HCl	1	1:10	Bray & Kurtz (1945)
CAL	0.1M Ca lactate 0.1M Ca acetate 0.3M acetic acid	120	1:20	Schuller (1969)
De-ionized water extract	De-ionized water	60	1:20	Olsen & Watanabe (1963)

P sorption experiment

To obtain information on P buffer capacity, a sorption experiment was conducted by equilibrating 5.0 g soil in a medium (soil:solution = 1:10) of 0.1M KCl containing increasing concentrations of P in the form of KH_2PO_4 . P levels used were 0, 20, 40, 60, 80, and 100 mg/l. The samples were equilibrated for 48 h in a mechanical shaker with intermittent shaking. After that, equilibration suspensions were centrifuged, and P in the supernatant solution (C) was determined by molybdenum blue method (Murphy and Riley, 1962). The amount of P sorbed (X) was calculated as the difference between the initial and the final P concentrations.

To evaluate the buffer capacity, the data obtained from the sorption experiment were fitted to the two-surface Langmuir equation:

$$X = \frac{K^I X_m^I}{1 + K^I C} + \frac{K^{II} X_m^{II}}{1 + K^{II} C}$$

Where;

- X = P sorbed per unit weight of soil
- K^I = Equilibrium constant at high bonding energy
- K^{II} = Equilibrium constant at low bonding energy
- X_m^I = Adsorption maximum at high bonding energy
- X_m^{II} = Adsorption maximum at low bonding energy
- C = Equilibrium P concentration

To derive the two-surface equations, X/C was plotted against X, and two straight lines that fitted best were selected (Sposito, 1982). Using the slopes and intercepts of these two straight lines, the four unknown parameters of the two-surface Langmuir equation, K^I, K^{II}, X_m^I, and X_m^{II} were determined. The maximum buffer capacity (MBC) values were calculated using the following equation (Holford and Mattingly, 1976),

$$MBC = K^I X_m^I + K^{II} X_m^{II}$$

RESULTS AND DISCUSSION

Soil properties

The important physical and chemical properties of experimental soils are given in Table 2. The soils were slightly acidic to strongly acidic in reaction (pH = 4.5-6.8). Most of the soils used in this study belong to sandy loam and loamy sand textural classes.

Table 2. Some physical and chemical properties of experimental soils.

Location	pH	CEC (meq/ 100g soil)	OM (%)	Texture	Exchangeable Ca (meq/100g soil)	MBC ($\mu\text{g P}$ sorbed/ $\mu\text{g P}$ solution)
Minipe	6.83	21.7	1.26	Sandy Loam	5.53	78.55
Naula	6.50	31.8	2.07	Loamy Sand	6.66	1854.60
Maha- Illuppallama	6.17	24.2	2.21	Sandy Loam	5.80	240.50
Giranduru- kotte	6.12	18.1	1.64	Loamy Sand	1.46	34.19
Dodan- golla	6.16	26.0	1.17	Sandy Loam	3.85	27.46
Nikawera- tiya	6.13	13.7	1.47	Loamy Sand	3.40	22.35
Pallama	6.05	14.6	0.31	Sand	0.69	11.90
Pelawatta	5.77	16.9	1.09	Sandy Loam	4.41	185.08
Udadum- bara	5.78	16.4	2.50	Sand	4.66	86.53
Matale	5.85	32.9	2.50	Sandy Loam	3.63	3060.60
Hunnas- giriya	5.80	25.0	3.16	Loamy Sand	0.91	233.80
Nuwara- eliya	5.03	41.9	5.36	Loamy Sand	1.20	5716.70
Lunuwila	5.77	22.7	0.85	Loamy Sand	0.80	05.30
Nanuoya	4.17	27.0	5.74	Loamy Sand	0.49	83.43
Kiribath- kumbura	4.93	17.6	1.53	Sand	1.19	870.88
Awissa- wella	4.65	15.3	2.50	Sand	0.43	421.40
Mawata- gama	4.83	19.3	1.52	Sandy Loam	1.00	208.57
Kegalle	4.73	22.3	3.69	Sandy Loam	0.34	2906.90
Nawala- pitiya	4.75	17.7	2.36	Loamy Sand	0.56	2310.90
Rathna- pura	4.50	21.3	2.55	Loamy Sand	0.21	433.60

CEC = Cation exchange capacity OM = Organic Matter

Phosphorus sorption parameters

Maximum buffer capacity values of twenty soils tested are given in Table 2. Nuwara Eliya, Matale, Kegalle, Nawalapitiya, and Naula soils were highly buffered (>1000), while Pallama and Lunuwila soils had very low buffer capacities (<15). Simple regression technique was used to study the

relationship between soil characteristics and MBC values. The parameters used were organic matter content, clay content, pH and cation exchange capacity. When all soils were considered, only CEC showed a significant relationship with MBC ($r=0.7^*$), whereas other parameters did not show significant relationships with MBC values.

Assessment of phosphorus availability

When all soils were considered, cumulative P uptake by rice plant and P quantity measured by all five extraction methods showed significant linear relationships (Table 3). It is evident from the Table 3 that Bray-2 method ($r=0.76^{**}$) was the best on an overall basis for all soils used in this study. Bray 2 extractant usually extracts the more rapidly soluble phosphorus as well as some of the unavailable forms of phosphorus (Williams and Knight, 1963).

Table 3. Relationship between cumulative P uptake and amount of P extracted by different methods.

Method	r value				
	All soils	pH>5	Soils with pH<5		
			Low MBC	High MBC	
Olsen P	0.67 [*]	0.76 [*]	0.14 ^{ns}	0.62 ^{ns}	0.83 ^{ns}
Bray-1 P	0.68 [*]	0.85 ^{**}	0.28 ^{ns}	0.79 [*]	0.10 ^{ns}
Bray-2 P	0.76 ^{**}	0.87 ^{**}	0.14 ^{ns}	0.87 ^{**}	0.10 ^{ns}
CAL P	0.73 [*]	0.88 ^{**}	0.20 ^{ns}	0.82 ^{**}	0.20 ^{ns}
De-ionized-water	0.73 [*]	0.81 [*]	0.28 ^{ns}	0.83 ^{**}	0.17 ^{ns}

* $P<0.05$; ** $P<0.01$

When soils with pH greater than five were considered separately, the relationship between P extracted and cumulative P uptake improved for all

five methods (Table 3), with CAL method giving the best value ($r = 0.88^{**}$). Similar observations were reported by Envezor (1977) and Kumaramage (1986). Possibly the buffering ability of acidic CAL extractant is better, since it contains acetic acid and calcium acetate, which enable the evaluation of phosphorus availability more accurately than other methods. There were no significant relationships between P uptake and P extracted by any of the methods for soils with pH less than 5.0 (Table 3). Therefore, none of the methods tested seem to be appropriate to assess P availability in strongly acidic soils of pH below 5.0.

Since the soils used in this study were slightly acidic to strongly acidic in reaction, Olsen extractant with a pH of 8.5 may not be very effective in assessing available P status ($r=0.67^*$) due to the pH difference between soil and extractant. However, the amount of P extracted by Olsen method was found to be significantly higher than the amount extracted by the other four methods (Table 4). This indicates that the absolute amount extracted does not always represent the P availability. The amount of P extracted followed the order Olsen > Bray-2 > Bray-1 > CAL > De-ionized water.

The quantity of P extracted by all five methods did not show a significant relationship with P buffer capacity values, which is an important determinant of P availability. Based on the MBC values, the soils used were arbitrarily grouped into soils with high and low P retention ability (>1000 and <1000 $\mu\text{g P sorbed}/\mu\text{g P solution}$), respectively. The relationship between P uptake and quantity of P extracted by different extraction methods were studied separately for soils with high and low P retention. The r values are given in Table 3. According to the values, none of the methods except Olsen method seem to be suitable to assess P availability in soils with high P retention. Suitability of Olsen method to assess P availability of soils with high P retention ability has to be studied further. Bray-2, CAL and De-ionized water methods seem to be more suitable for estimating P availability in soils with low P retention.

Table 4. Amount of P extracted by different methods and cumulative P uptake values.

Soil	Olsen	Bray-1	Bray-2	CAL water	De-ion. Uptake	Cum. P
Minipe	2.9	0.68	1.29	0.54	0.07	2.09
Naula	1.15	0.34	0.55	0.19	0.06	1.88
Mahalluppallama	1.35	0.14	0.22	0.12	0.10	1.81
Girandurukotte	2.49	0.88	1.31	0.61	0.10	2.15
Dodangolla	1.50	0.31	0.92	0.29	0.06	2.25
Nikaweratiya	4.40	1.99	6.04	1.96	0.47	2.85
Pallama	1.05	0.18	0.22	0.15	0.05	2.24
Palawatta	2.40	0.39	0.46	0.33	0.07	2.13
Udadumbara	0.99	0.32	0.37	0.26	0.04	2.04
Matale	0.65	0.07	0.29	0.04	0.03	1.84
Hunnas	1.15	0.32	0.35	0.29	0.03	2.15
Nuwaraceliya	1.99	0.69	0.89	0.61	0.03	2.16
Lunuwila	0.95	0.20	0.45	0.12	0.08	2.06
Nanuoya	2.10	0.91	1.66	0.83	0.04	2.09
Kiribathkumbura	1.60	0.06	0.11	0.04	0.03	2.33
Awissawella	2.35	0.25	0.29	0.19	0.03	2.01
Mawatagama	0.75	0.07	0.22	0.06	0.03	2.18
Kegalle	1.25	0.53	0.55	0.39	0.03	2.02
Nawalapitiya	0.85	0.29	0.42	0.19	0.03	1.80
Rathnapura	1.71	0.32	0.37	0.26	0.03	2.07

CONCLUSIONS

According to the results of this experiment, none of the methods tested were appropriate to assess P availability of soils with pH less than 5. CAL method was the most suitable for soils with pH greater than 5.0. Bray-2, CAL and De-ionized water methods seem to be more appropriate for estimating P availability in soils with low P retention. Bray-2 method was the most suitable extractant to assess P availability in soils with a wide range of chemical properties.

ACKNOWLEDGEMENTS

The authors wish to acknowledge NARESA for financial support.

REFERENCES

- Bray, N.C. and Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.* 95: 39-45.
- Champman, H.D. and Pratt, P.F. (1961). *Methods of Analysis for Soils, Plants and Waters.* Division of Agric. Sci. University of California, Riverside, USA: 161-175.
- Envezor, W.O.(1977). Soil testing for phosphorus in some Nigerian soils. I. Comparison of methods of determining available P in soils of South Western Nigeria. *Soil Sci.* 123: 48-53.
- Gunary, D. and Sutton, C.D. (1967). Soil factors affecting plant uptake of phosphate. *J. Soil Sci.* 18: 167-173.
- Holford, I.C.R. and Mattingly, G.E.G. (1976). A model for the behaviour of labile phosphate in soil. *Plant and Soil* 44: 219-229.
- Kamprath, J. and Watson, M.E. (1980). Conventional soil and tissue tests for assessing the Phosphorous States of soil. In: Khasawneh, F.F. (Ed). *The Role of Phosphorus in Agriculture.* Am. Soc. Agron. Madis, Wisconsin, USA.
- Kumaragamage, D. (1986). Studies on the availability of P in four soils of Sri Lanka. Unpublished M.Phil. thesis, Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.
- Mengel, K. (1985). Dynamics and availability of major nutrients in soils. *Adv. Soil Sci.* 2: 65-131.
- Murphy, J. and Riley, J.P. (1962). *Anal. Chem. Acta.* 27; 31. In Hesse, P.R.(1971). *A Text book of soil Chemical Analysis,* John Murray (Publishers) Ltd. London.
- Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954). Estimation of available phosphorus by extraction with sodium bicarbonate. *US Dept. Agric. Circular* 939.
- Olsen, S.R. and Watanabe, F.S.(1963). Diffusion of phosphorus as related to soil texture and plant uptake. *Soil Sci. Soc. Am. Proc.* 27: 648-653.
- Sposito, G. (1982). On the use of the Langmuir equation in the interpretation of the "adsorption" Phenomena II. The two surface Langmuir equation. *Soil. Sci. Soc. Am. J.* 46: 1148-1152.
- Shuller, H. (1969). Di CAL-Method, eine neue Method zur Bestimmung des pflanzenverfugbaren phosphates in Boden. *Z. Pflanzenernahr. Dung. Bodenkd.* 123: 48-63.
- Williams, E.G. and Knight, A.H. (1963). Evaluation of phosphate status by pot experiments, conventional extraction methods and labile phosphate values estimated with the aid of P-32. *J. Sci. Food. Agric.* 14: 555-563.