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Predicting Phosphorus Buffer Coefficients of Representative Maize Soils in Laos

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ABSTRACT

Maize is an important crop in the Lao Peoples Democratic Republic (Laos) with as much as 113,808 ha grown in 2006. Recent research indicates that nearly all soils growing maize are deficient in phosphorus. In order to quantify the phosphorus requirement using the phosphorus decision support system (PDSS), the most important factor in the PDSS algorithm is the phosphorus buffer coefficient (PBC), which reflects the reaction of the soil to P fertilizer. The PBC was studied in 15 upland soils using the Bray 2 ($PBC_{Bray\ 2}$) and Mehlich 1 ($PBC_{Mehlich\ 1}$) methods and the iron oxide impregnated filter paper or Pi test ($PBC_{Pi\ test}$) procedure. Multiple regression analysis was used to quantify the relationship between the PBC and some soil properties involved in the P-sorption process. The $PBC_{Bray\ 2}$ and $PBC_{Mehlich1}$ results were significantly correlated at the 0.01 level with organic carbon and iron having an adjusted R^2 of 0.79 and 0.86 determined by the citrate bicarbonate dithionite method and the amount of clay, respectively. Unlike the two chemical extractions, the $PBC_{Pi\ test}$ result was significantly correlated at the 0.01 level with aluminum (determined by the method using ammonium oxalate at pH 3 in darkness), the percent clay and organic carbon with an adjusted R^2 of 0.80. However, the study suggested that the PBC should be estimated by the Mehlich 1 method, so that the model could more accurately predict the PBC.

Key words: phosphorus buffer coefficient (PBC), Laotian soils, PBC and soil properties

INTRODUCTION

Maize has become the second most important crop in Laos with 86,000 ha grown in 2005, 113,815 ha in 2006 and 137,145 ha in 2007 (National Statistics Center, 2005, 2006, 2007); thus, it is becoming increasingly important. Nevertheless, yields are low in some areas because of inadequate fertilization. Phosphorus plays an important role in maize production on Laotian soils. The phosphorus decision support system (PDSS) developed by Yost *et al*. (1992) can be used to establish a P fertilizer recommendation that is a site-specific, so that the cost of crop production and the environmental impact are reduced. The phosphorus buffer coefficient (PBC) is an important factor in the PDSS software. The PBC is the reactivity coefficient of a soil with P fertilizer added. The measurement of the PBC can be done using a regression of the extractable P and applied P (Chen *et al.,* 1997). At present, the PBC is predicted by an equation that relates PBC with only the soil clay content percentage, as proposed by Cox (1994). Nevertheless, it might not be satisfactory for soils with different properties and relatively high clay content, such as the upland soils of Laos. Wang *et al*. (2000) proposed the inclusion of physical soil properties, such as the P

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sorption site density and reactive mass, to improve the efficiency of PBC predictions. The procedure used in such analysis is costly and impractical for the routine laboratory. Consequently, the development of a simpler approach is required. The extractable P used in the P prediction equation must be obtained from the same soil P testing method as the PBC. The estimation of the PBC by numerous methods would provide prospective users with several alternatives. In Laos, Bray 2 extraction is commonly used to estimate the available P. However, there are no studies of the correlation between P extraction methods and plant uptake. In Thailand, the Bray 2 and Mehlich 1 methods have been found to correlate well with total P uptake by maize (Attanandana *et al.*, 1999). A major disadvantage in using extraction solutions, however, is that they may mobilize not only plant-available P but also some otherwise stable and non-labile soil P. One new and innovative method that does not have the limitation of extracting solutions is the iron oxide impregnated filter paper procedure (Pi test) (Sissingh, 1983). The Pi test is unique in this respect because the iron oxide impregnated filter paper does not react with the soil, but acts as a sink for the soil solution P. More recently, Hosseinpur and Ghanee (2006) found that the amount of P extracted by the Pi test was significantly correlated with the P uptake of corn (*Zea mays* L.), unlike that extracted by the Olsen, Colwell, Mehlich1, 0.01 M $CaCl_2$, AB-DTPA and 0.1 *M* HCl methods. The objective of this study was to relate the PBC estimated by the Bray 2 and Mehlich 1 methods and the Pi test with soil properties which affect the P sorption process, using stepwise multiple regressions.

MATERIALS AND METHODS

Fifteen soils, representing the major upland maize soils of Laos were selected from the Pasai (Psi), Pek (Pe), Kham (Kha), Pookood (Pkd), Koon (Kn), Pookoon (Pkn), Paklay (Pl), Kentao (Kt), Borten (Bt), Kasi (Ks), Bachieng (Bc), Tabok (Tb), Paksong (Pso), Salavanh (Sv) and Sekong (Sk) districts. Surface soil samples (0-20 cm depth) were collected from each location, air-dried, ground to pass through a 2-mm sieve and thoroughly mixed. All samples were analyzed for selected soil properties (Table 1).

Phosphorus buffer coefficients of upland maize soils

Each soil sample was amended with potassium dihydrogen phosphate (KH_2PO_4) at the rates of 0, 25, 50, 100, 200 and 400 mg P kg^{-1}. The soil mixtures were then moistened with deionized water to field capacity (depending on each soil) and incubated at 30°C for 2 weeks. The extractable P was analyzed by three procedures, the Bray 2 and Mehlich 1 methods and the Pi test.

Predicting PBC using soil properties

Stepwise multiple linear regression analysis was used to select the soil properties that best related to the PBC obtained by the three procedures.

RESULTS AND DISCUSSION

Characteristics of the selected soils

The 15 upland maize soils were Ultisols (Psi, Pe, Kha, Pkd, Pkn, Bt, Sv, Bc, Tb and Pso), and Alfisols (Kn, Ks, Pl, Kt, Sk). The soils were predominantly acidic with soil pH values ranging from 4.5 to 5.9; the soil textures were also different. The soils had low organic carbon (7.0-22.9 g kg^{-1}), low available P (ranging from 0.68 to 4.62 mg kg^{-1} using the Bray 2 method), except for the Pookood (Pkd) soil, which had high available P values from all three procedures (Table 1).

Soil samples were divided into two groups. Group 1 consisted of soils containing a high percentage of clay (ranging from 363 to 709 g kg^{-1}), high Fe and Al determined by the citrate bicarbonate dithionite method (Fe_d and Al_d)

Table 1 Some properties of selected soils.

Group	Soil name	Soil property											
		Texture[1]	Clay[1] ($g\ kg^{-1}$)	pH[2]	OC[3] ($g\ kg^{-1}$)	CEC[4] ($cmol_c\ kg^{-1}$)	P[5] ($mg\ kg^{-1}$)	P[6] ($mg\ kg^{-1}$)	P[7] ($mg\ kg^{-1}$)	Fe_d[8] ($g\ kg^{-1}$)	Fe_o[9] ($g\ kg^{1}$)	Al_d[8] ($g\ kg^{-1}$)	Al_0[9] ($g\ kg^{-1}$)
	Koon (Kn)	Clay	430	5.3	14.5	14.2	0.52	0.31	0.40	31.8	2.64	6.24	1.05
	Pookoon (Pkn)	Clay	553	4.9	22.4	31.7	1.19	0.61	0.40	61.8	5.09	17.46	6.08
	Kentao (Kt)	Silty clay	456	5.9	21.9	28.3	1.35	0.88	1.12	51.0	5.28	2.56	0.88
	Kasi (Ks)	Clay loam	363	5.9	19.6	22.1	1.04	0.61	1.62	125.5	5.44	12.35	5.88
1	Bachieng (Bc)	Clay	669	4.6	14.1	17.5	4.54	1.17	1.01	26.8	2.78	4.88	2.38
	Tabok (Tb)	Clay	582	5.8	19.4	14.2	4.62	1.29	3.84	66.1	6.25	11.42	6.12
	Paksong (Pso)	Silty clay	426	4.8	22.9	25.4	3.52	0.82	2.81	99.6	7.62	30.56	9.45
	Salavanh (Sv)	Clay	709	4.6	18.7	25.0	2.11	0.87	2.15	97.0	5.92	12.28	4.50
	Sekong (Sk)	Silty clay loam	513	5.3	21.5	32.1	0.68	0.16	0.87	88.0	7.96	19.22	6.88
	Pasai (Psi)	Loam	222	4.8	19.1	18.8	3.04	0.87	0.78	10.0	2.87	8.30	8.26
	Pek (Pe)	Clay loam	323	4.5	22.4	12.1	1.46	0.85	0.60	21.8	3.91	7.65	3.07
2	Kham (Kha)	Sandy loam	179	5.4	7.0	4.3	3.04	1.69	1.87	12.8	2.26	3.33	0.96
	Pookood (Pkd)	Loam	245	4.8	21.8	12.1	24.32	8.89	7.22	18.2	8.52	4.61	2.26
	Paklay (Pl)	Silty clay loam	344	5.8	19.8	23.8	2.80	1.49	1.66	23.8	4.52	1.97	0.76
	Botaen (Bt)	Silty clay loam	363	4.8	10.6	16.3	1.24	0.72	0.90	16.7	3.03	1.09	1.47

[1] Pipette method (Day, 1965)

[2] Glass electrodes (soil: water, 1:1)

[3] Walkley and Black titration (Walkley and Black, 1934)

[4] NH_4OAc, pH 7, replacement method (Rhoades, 1982)

[5] Bray 2 method (Bray and Kurtz, 1945)

[6] Mehlich 1 method (Mehlich, 1953)

[7] Pi test (Myers *et al.*, 1995; Chardon *et al.*, 1996; Chardon, 2000)

[8] Citrate bicarbonate dithionite method (Loeppert and Inskeep, 1996)

[9] Method using ammonium oxalate at pH 3 in darkness (Loeppert and Inskeep, 1996)

(ranging from 26.8 to 125.5 and 2.56 to 30.56 g kg^{-1} respectively) and high Fe and Al extracted by ammonium oxalate (Fe_o and Al_o) (ranging from 2.64 to 7.96 and 0.88 to 6.88 g kg^{-1} respectively). Soils in this group were: Tb, Pso, Sv, Sk, Pkn, Kn, Kt, Ks and Bc. Group 2 soils contained less clay, low Fe_d and Al_d (in the range 10.0 to 23.8 and 1.09 to 8.30 g kg^{-1} respectively) and low Fe_o and Al_o (in the range 2.26 to 8.52 and 0.76 to 8.26 g kg^{-1}, respectively). , Soils in this group were: Bt, Psi, Pe, Kha, Pkd, and Pl.

PBC studies

The soils in Group 1, except for Bc, (Tb, Pso, Sv, Sk, Ks, Pkn, Kn and Kt) had low PBC values, from all three methods; a high amount of clay and Fe_d was observed in these soils. The PBC values of the Group 2 soils were higher than the Group 1 soils. The PBC was different between the soil series and among the soil P testing methods. The values for the $PBC_{Bray\ 2}$, $PBC_{Mehlich\ 1}$ and $PBC_{Pi\ test}$ procedures were in the range 0.11 to 0.76, 0.06 to 0.56 and 0.05 to 0.34, respectively (Table 2).

The PBC from the Bray 2 method had the highest value among the three methods because the Bray 2 method was higher in acid concentration than the Mehlich 1 and Pi test procedures. The $PBC_{Pi\ test}$ value in all soils was the lowest, because this procedure used the adsorption of P in soil solution on the FeO paper. Among the soil series, soils from Kham (Kha) and Pookood (Pkd) districts had the highest PBC values from all procedures, possibly because these soils had the lowest amount of clay (179 and 245 g kg^{-1}, respectively). Consequently, they had less capacity to adsorb P.

The relationship of PBC and soil properties

Statistical models of the PBC estimated by the three different extraction procedures showed different independent variables, namely, organic carbon (OC), the amount of clay, iron determined by the citrate bicarbonate-dithionite method (Fe_d) and aluminum determined by ammonium oxalate (Al_o) (Table 3). The difference in the independent variables in each model was attributed to the effect of the soil P testing methods.

Table 2 Phosphorus buffer coefficients of the soils.

Group	District names	Phosphorus Buffer Coefficient (PBC) by Procedure		
		Bray 2	Mehlich 1	Pi test
1	Koon (Kn)	0.22	0.16	0.14
	Pookoon (Pkn)	0.19	0.11	0.05
	Kentao (Kt)	0.17	0.13	0.11
	Kasi (Ks)	0.11	0.08	0.06
	Bachieng (Bc)	0.32	0.23	0.14
	Tabok (Tb)	0.14	0.06	0.08
	Paksong (Pso)	0.05	0.02	0.03
	Salavanh (Sv)	0.10	0.02	0.06
	Sekong (Sk)	0.07	0.02	0.03
2	Pasai (Psi)	0.38	0.19	0.07
	Pek (Pe)	0.46	0.24	0.11
	Kham (Kha)	0.76	0.56	0.34
	Pookood (Pkd)	0.42	0.25	0.21
	Paklay (Pl)	0.33	0.22	0.28
	Botaen (Bt)	0.40	0.39	0.28

Predictions of values for the PBC_{Bray-2} (model 1) and $PBC_{Mehlich-1}$ (model 2), using OC, Fe_d and the amount of clay could explain 79% and 86% of the variability, respectively.

The variables Al_o, OC and the amount of clay could explain 80% of the variability in the $PBC_{Pi-test}$ (model 3). Unlike the $PBC_{Bray\ 2}$ and $PBC_{Pi\ test}$ models, the $PBC_{Mehlich\ 1}$ model showed the highest correlation with some soil properties.

The first reason for the highest correlation was due to the effect of soil organic carbon. Havlin *et al*. (2005) reported that organic anions produced from OM decomposition formed stable complexes with Fe and Al that prevented their reaction with $H_2PO_4^-$. Giesler *et al.* (2005) reported that dissolved organic carbon released in solution was positively correlated with phosphate sorption. Similarly, Alcantara *et al*. (2008) reported that the remaining P in the soil solution was strongly dependent on the clay and soil organic matter content.

The second reason for the highest correlation was the amount of Fe, Al and clay content. Since phosphate is an anion, any particle that generates anion exchange capacity (such as AlO and FeO under acidic conditions, in highly weathered kaolinitic clay and amorphous materials), will form strong bonds with the phosphate (University of Hawaii, 2008).

Bear (1964) stated that the anion adsorption was intimately connected with the nature of the soil colloids and with the pH of the system. All of the soils were acidic; as the amount of Fe increased, more soil P was sorbed, thus decreasing PBC values.

Wiriyakitnateekul *et al*. (2005) reported that the variability in P sorption by Thai soils could be explained by a combination of Fe_d, Fe_o, Al_d and Al_o. Zhang *et al*. (2003) also confirmed that the P availability of flooded rice soils was largely controlled by the transformation of Fe, from the crystalline to amorphous form, indicating that poorly crystalline and amorphous forms of Fe played a primary role in P sorption by soils. The greater surface area of amorphous Fe was responsible for more soil P sorption. In addition, soils containing large quantities of clay will fix more phosphorus than soils with small amounts of clay (Tisdale *et al*., 1985). However, phosphorus sorption also depends on the mineral type of the clay. For example, kaolinite, which contains hydroxyl groups, is able to adsorb phosphorus ions in greater amounts (Millar, 1955). Phosphate adsorption takes place by replacing the hydroxyl ions exposed at the edges or other surfaces of silicate clays minerals or oxide minerals (Troeh and Thompson, 2005), especially if the soil colloids are primarily Fe and Al oxides. Wang *et al*. (2000) studied the PBC using potential sorption site density and soil aggregate size, and found that in some cases, soils that were different in the P sorption site density were not different in the PBC. Thus, they suggested that PBC prediction should include other soil characteristics. A study on rice soils (Hongthana *et al.,* 2007) showed that values of $PBC_{Bray\ 2}$ and $PBC_{Mehlich\ 1}$ were highly correlated with organic matter and Fe_d.

PBC prediction from soil properties

Some soil properties were substituted into models 1, 2 and 3 to predict values for $PBC_{Bray\ 2}$, $PBC_{Mehlich\ 1}$ and $PBC_{Pi\ test}$, respectively.

Table 3 Models and coefficients describing the PBC prediction of maize soils.

Model	Statistical model	$AdjR^2$	RSS
1	$PBC_{Bray\ 2}$ = 0.837-0.004clay-0.002Fe_d-0.137OC	0.79**	0.08
2	$PBC_{Mehlich\ 1}$ = 0.695-0.003clay-0.001Fed-0.17OC	0.86**	0.02
3	$PBC_{Pi\ test}$ = 0.440-0.002clay-0.017Al_o-0.076OC	0.80**	0.03

** significant at the 0.01 level.

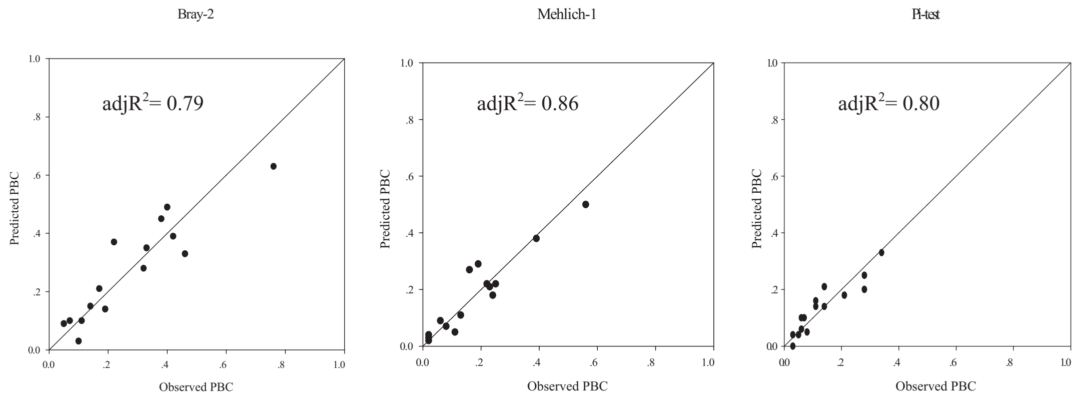

Figure 1 The 1:1 relationship of predicted and observed PBC by the three extraction procedures.

The predicted PBC was plotted against the observed PBC to study the accurate estimation of PBC using a 1:1 linear relationship (Figure 1). The relationship depicted in Figure 1 shows that the predicted and observed PBC by the Mehlich 1 and Pi test procedures were very similar. The residual sum of squares (RSS) was calculated as an indication of the variation of the predicted and observed PBC of the three extraction procedures.

The results showed that the RSS of the predicted and observed PBC values by the Bray 2, Mehlich 1 and Pi test procedures was 0.08, 0.02 and 0.03, respectively. The Mehlich 1 and Pi test procedures were similar in adjusted R^2 and RSS. The Mehlich 1 procedure was simpler and more rapid compared to the Pi test procedure. Thus, the Mehlich 1 method was proposed as the best extraction method for PBC prediction in this study.

CONCLUSIONS

The phosphorus buffer coefficient (PBC) obtained from selected upland Laotian soils depended on different independent variables, such as Fe_d, Al_o, percent of clay content and soil organic carbon. Values for $PBC_{Bray\ 2}$ and $PBC_{Mehlich\ 1}$ were significantly correlated at the 0.01 level with Fe_d, clay and organic carbon with adjusted R^2 values of 0.79 and 0.86, respectively. The $PBC_{Pi\ test}$ procedure was significantly correlated at the 0.01 level with Al_o, clay content and organic carbon with an adjusted R^2 value of 0.80. The results of the study suggested that the PBC of selected Laotian soils should be estimated by the Mehlich 1 method because this method had the highest correlation with soil properties and the lowest residual sum of squares. The 1:1 linear relationship showed the best fit of predicted and observed PBC values using the Mehlich 1 method. Furthermore, this method was simple and inexpensive for routine analysis in Laotian laboratories.

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