

Predicting Phosphorus Buffer Coefficients of Some Representative Soils for Maize Production in Lao PDR by Three Soil Analysis Methods

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ABSTRACT

Phosphorus buffer coefficient (PBC) is one of the important factors in the phosphorus fertilizer recommendation prediction by the use of Phosphorus Decision Support System (PDSS) program. A study on PBC of 7 representative maize soils in Laos and one Thai soil was conducted. The PBC determination was done by mixing the soils with potassium dihydrogen phosphate (KH_2PO_4) at the rates of 0, 25, 50, 100 and 200 mg P kg^{-1} . All soil samples were kept in the incubator at 30 °C for two weeks. The extractable P was analyzed by three methods: Bray-2, Mehlich-1 and iron oxide-impregnated filter paper method or Pi-test. The results showed different PBC values of soils with different extractants. Multiple regression analysis was used to determine the relationship between the PBC and soil properties. It revealed that $\text{PBC}_{\text{Bray-2}}$ was correlated with percentage of clay content with $\text{adjR}^2=0.64$ and $\text{PBC}_{\text{Pi-test}}$ was correlated with percentage of clay content and ammonium oxalate extractable aluminum, with $\text{adjR}^2=0.89$. The soil properties were substituted in the two models to predict the $\text{PBC}_{\text{Bray-2}}$ and $\text{PBC}_{\text{Pi-test}}$, respectively. The predicted PBC was plotted against observed PBC to compare the prediction accuracy using soil properties by 1:1 line relationship. The result showed that the PBC should be estimated by Pi-test for more accurate PBC prediction.

Key words: phosphorus buffer coefficient, maize soils, phosphorus sorption, iron oxide-impregnated filter paper method

INTRODUCTION

The rates of recommended phosphorus fertilizer for maize production in the Lao People's Democratic Republic (Lao PDR) are not widely known. The major problems of maize production are the infertile soils with high soil acidity and low phosphorus content. Fertilizer application for maize production is very different in different production areas depending on the economy of the

farmers rather than on the nutrient needs of the plants (Lathvilayvong, 2000). The soils in the country are poor in nutrients, the organic matter (<0.2%), extractable P and K (<10, <40 mg kg^{-1}) cover about 87, 97 and 71%, respectively, of the total cultivated area (Vonghachack, 2000). In Thailand, the new technology for phosphorus and potassium fertilizer requirement prediction using Phosphorus Decision Support System (PDSS) program has been successfully used for maize

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production. The use of the decision-aids has resulted in reduced P fertilizer applications, and the farmers accepted the recommendations (Attanandana *et al.*, 2000). Phosphorus buffer coefficient (PBC) is an important variable in the PDSS program (Chen *et al.*, 1997). In Thailand, Bray-2 extraction is widely used to estimate soil available P. Mehlich-1 method, a dilute double acid extractant was used in the sandy soils of the eastern coastal plain of USA (Jones, 1985). Both of these methods are found to correlate well with total P uptake of maize (Attanandana *et al.*, 1999). Yost *et al.* (1992) suggested that characterization of the buffer coefficient should be possible by quantifying soil properties that determine P sorption. Wright *et al.* (1992) estimated P buffering coefficient by relating the P buffering coefficient to soil pH and P retention as estimated by Saunders (1965)'s method. Hughes and Gilkes (1994) and Cox (1994) predicted P buffering coefficient by clay content in the soil. Smyth and Sanchez (1982) proposed that the soils having the highest clay and free Fe_2O_3 contents had the highest P sorption capacity. Soil pH significantly influences other soil chemical properties. Brady (1990) suggested that, when the pH falls below 6.0, the availability of nutrients such as phosphorus, potassium, calcium, and magnesium decreases. Phosphate availability also tends to decrease at high soil pH, because of precipitation as insoluble calcium phosphate compounds. The pH range of the greatest phosphate availability is about 6 to 7 for most agricultural soils (Bohn *et al.*, 1985). Also Shahandeh *et al.* (1994) observed that soil with high levels of oxalate extractable Fe sorbs more P under reduced conditions.

The objective of this study was, therefore, to study the PBC of eight representative soils for maize production in Laos and Thailand by the use of Bray-2, Mehlich-1 and Pi-test methods. More over, the study on relationship of PBC with soil properties using stepwise multiple regression analysis was also included.

MATERIALS AND METHODS

Soils

Eight soil samples were taken in October, 2006. Seven soils representing the important soils for maize production in the Lao PDR were selected from different locations for the experiment. They were Hoysai soil (Hs) which was collected in Hoysai district, Borkeo province. Two soil samples, Pek soil (Pe) and Phasay soil (Ps) were collected in Pek and Phasay districts, Xiengkhouang province. Saythong soil (St) was collected in Nasaythong district, Vientiane province. Vapi soil (Vp) was collected in Vapi district, Saravanh province. Two soil samples, Bachieng soil (Bc) and Hoythakuane soil (Hk) were collected in Bachieng and Pathomphone district, Champasak province, respectively. In addition, Khon Kean (Kk) soil from Thailand was included. Most soils from Laos and that from Thailand are Ultisols except Bc soil which is Oxisol. All soil samples were collected from the horizon, at 0-20cm depth. Air-dried soil samples were ground and passed through a 2-mm sieve and thoroughly mixed.

Soil analysis

Soil analysis was conducted in the laboratory of Department of Soil Science, Faculty of Agriculture, Kasetsart University, Thailand in December, 2006. Soil physical and chemical properties were determined as follows; soil texture was determined by pipette method (Day, 1965), soil pH by glass electrode (soil water ratio 1:1), soil organic matter by Walkley and Black (1934), and cation exchange capacity (CEC) by ammonium acetate (pH 7) method (Rhoades, 1982). Extractable Al and Fe were measured by acid ammonium oxalate (pH 3), and citrate-bicarbonate-dithionite methods (Loeppert and Inskeep, 1996). Available P was extracted by Bray-2, (Bray and Kurtz, 1945). Mehlich-1 (Mehlich, 1953), and Pi-test methods (Myers *et al.*, 1995;

Chardon *et al.*, 1996; Chardon, 2000). Total N was analyzed by Kjeldhal method (Bremner, 1996).

Phosphorus buffer coefficient (PBC) of soils

Soil incubation

Five-gram of each soil sample was mixed with potassium dihydrogen phosphate (KH_2PO_4) at the rates of 0, 25, 50, 100 and 200 mg P kg^{-1} . The soil mixtures were then added with distilled water to field capacity. All soil samples were kept in the incubator at 30 °C for two weeks. The extractable P was then analyzed by the three methods mentioned above.

PBC calculation and correlation with soil properties

Phosphorus buffer coefficients (PBC) were estimated from the slope of linear regression of extractable P versus P added after 2 weeks of incubation. The PBC values of each soil from the three methods were correlated with some soil properties using stepwise multiple regression analysis.

Iron oxide-impregnated filter paper method (P-test)

FeO paper preparation: A 5.5-cm disc of ash free, hard filter paper Whatman no 50 (2.7 μm pore openings) as proposed by Myers *et al.* (1995) was immersed in acidified 0.65 M FeCl_3 for 5 minutes (Chardon, 2000). The paper was drip dried at room temperature for 1 hour. The paper was then treated with NH_3 vapor through a bath containing 5% of NH_4OH until the paper color changed from yellow to brown (Chardon *et al.*, 1996). Since NH_4Cl can lower pH level, causing the increase of P concentration in soil solution, the FeO paper was washed with distilled water several times to get rid of NH_4Cl . After air-dried, the paper was kept in the closed pack.

Shaking soil suspension with FeO paper: one gram of soil was shaken with 40 ml of 0.01 M of CaCl_2 solution. One FeO paper protected by

polyethylene screen with 0.1 mm opening in a fix position was shaken with soil suspension on a reciprocating shaker at a speed of 130 excursions min^{-1} for 16 hours. The paper was taken out and thoroughly rinsed with distilled water to remove adhering soil particles (Myers *et al.*, 1995).

Determination of P extracted by FeO paper: The FeO with adsorbed P was dissolved by shaking in 40 ml of 0.1 M H_2SO_4 for 1 hour (Habib *et al.*, 1998). The amount of P in the soil extract was determined using the ammonium molybdate method, with ascorbic acid as the reducing agent (Murphy and Riley, 1962).

RESULTS AND DISCUSSION

Properties of selected soils

All soils were predominantly acidic with pH ranging from 4.3 to 5.5. The clay content of these soils was higher than 20%, except Kk soil which was very low in clay content (6.3%). The amount of Fe_d and Al_d content of Bc soil were highest among the soils studied. Available P of Hs soil extracted by Bray-2, Mehlich-1 and Pi-test were obviously higher than those of the other soils (Table 1).

Phosphorus buffer coefficient (PBC)

A phosphorus buffer coefficient is an indicator of the change in extractable P per unit change of P added. In this study, the PBC values of each soil from the three methods were different. The PBC values of Kk soil from the three methods were higher than those of the other soils (Table 2). This high PBC indicated the lower P sorption. The Kk soil had lower clay content than the other soils. The PBC of Bc, Ps and Vp soils by three extractants were lower than other soils. It was noted that the clay content, amount of Fe_d and Al_d in Bc soil, Al_d in Ps and Vp soils were relatively higher compared to the other soils (Table 1). Clay mineral, and extractable Al, Fe by dithionite play important role in P fixation

Table 1 Characteristics of eight soil samples before conducting experiments.

Soil properties	Contents							
	Hs	Bc	Pe	Ps	Vp	Hk	St	Kk
Texture ¹	SL	C	SCL	SL	CL	SCL	CL	S
Clay (%) ¹	24.5	40.7	27.0	21.5	57.4	20.3	28.9	6.3
Soil pH ²	5.5	4.3	4.6	4.8	5.5	4.7	5.3	4.4
OM ³ (g kg ⁻¹)	21.1	49.6	55.2	54.1	16.6	12.7	30.0	8.6
CEC (cmol _c kg ⁻¹) ⁴	14.6	24.7	17.8	22.4	20.6	8.6	17.8	3.0
Total N ⁵ (g kg ⁻¹)	0.6	0.8	1.0	1.8	0.5	0.4	0.8	0.2
Total P ⁶ g kg ⁻¹	4.5	1.9	2.4	4.0	2.6	3.2	3.9	0.0
P (mg kg ⁻¹) ⁷	41.2	1.6	1.8	6.3	0.3	0.4	14.7	6.3
P (mg kg ⁻¹) ⁸	15.6	0.1	0.2	0.7	0.1	0.2	4.1	3.4
P (mg kg ⁻¹) ⁹	18.0	4.2	3.3	3.6	0.8	2.0	4.8	3.0
Fe _o (g kg ⁻¹) ¹⁰	3.1	2.9	1.6	0.9	2.6	1.5	2.2	0.6
Fe _d (g kg ⁻¹) ¹¹	11.9	55.2	16.5	2.6	13.1	9.0	9.6	1.2
Al _o (g kg ⁻¹) ¹²	0.8	3.6	1.6	5.6	1.6	1.2	2.7	0.4
Al _d (g kg ⁻¹) ¹³	23.3	31.5	28.2	27.8	27.9	25.2	27.4	27.5

¹ Pipette method (Day, 1964)² Glass electrodes, 1:1 soil: water;³ Walkley Black titration (Walkley and Black, 1934)⁴ NH₄OAc, pH7 replacement method (Rhoades, 1982)⁵ Macro Kjeldhal method (Bremner, 1996)⁶ Conc. HNO₃-H₂SO₄-HClO₄, ratio 5:1:2 (Yoshida *et al.* 1972)⁷ Bray-2 method (Bray and Kurtz, 1945)⁸ Mehlich-1 method (Mehlich, 1953)⁹ Pi-test method (Myers *et al.*, 1995; Chardon *et al.*, 1996; Chardon, 2000)^{10, 12} Acid ammonium oxalate method (Loeppert and Inskeep, 1996)^{11, 13} Citrate-bicarbonate-dithionite method (Loeppert and Inskeep, 1996)

(Agbenin, 2003). In the same way Wiriyaakitnateekul *et al.* (2005) reported that in Thai soils, 81% of variability in P sorption was related with extractable Fe and Al_i by dithionite and oxalate extraction. The PBC values of all soils which were estimated by Bray-2 and Pi-test methods were higher than PBC values estimated by Mehlich-1 except Kk soil of which the PBC value was highest with Mehlich-1 extractant.

Predicting PBC using soil properties

The correlation of soil properties with PBC values were determined by stepwise multiple regression analysis. The soil properties affecting the PBC calculation in each method were different with different methods. In model (1), PBC_{Mehlich-1} was not correlated with any soil properties. The PBC_{Bray-2} was correlated with % clay content alone with adjR² of 0.64. The percentage of clay

and Al_o were the main factors affecting the PBC_{Pi-test} with adjR² of 0.89 (Table 3).

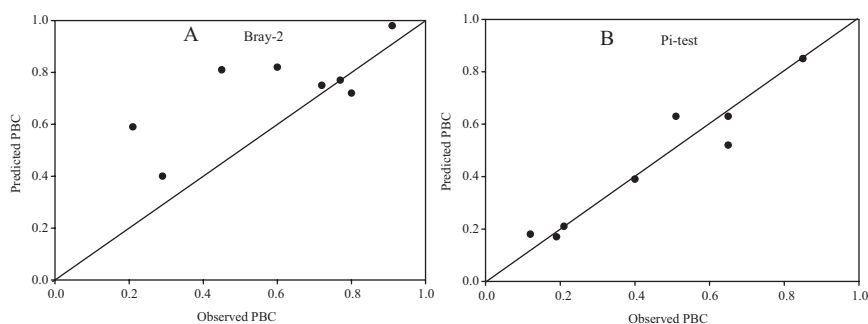
To describe relationships between the soil properties and PBC values, the clay and Al_o were important soil properties influencing PBC for the two models. In the model (2), PBC_{Bray-2}

Table 2 PBC values of 8 soil samples determined by the use of three different extraction methods.

Soils	Bray-2	Mehlich-1	Pi-test
Hs	0.77	0.17	0.65
Bc	0.21	0.03	0.12
Pe	0.72	0.13	0.65
Ps	0.45	0.12	0.19
Vp	0.29	0.07	0.21
Hk	0.60	0.31	0.51
St	0.80	0.22	0.40
Kk	0.91	0.99	0.85

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

Statistical model	adjR ²
(1)PBC _{Mehlich-1} no correlation with soil properties	-----
(2) PBC _{Bray-2} =1.05283-0.01139% clay	0.64*
(3) PBC _{Pi-test} =0.95750-0.01018% clay -0.10181 Al _o	0.89**

**Figure 1** Relationships of predicted and observed PBC by two different models.

decreases with increasing % clay content. Wang *et al.* (2000) observed that clay content had little correlation with PBC but high correlation of P sorption capacity with the amorphous materials, mainly Al and Fe oxides. Poudel and West (1999) reported that the maximum phosphate sorption of Oxisols, Ultisols and Inceptisols in Philippines ranged from 6,944 to 14,208 $\mu\text{g P g}^{-1}$ and it was closely related with Al_o and clay content. Model (3), PBC_{Pi-test} was correlated with % clay content and Al_o with adjR² of 0.89. Bruland and Richardson (2004) found that Al_o had the highest correlation with phosphorus sorption index. Also Maguire *et al.* (2001) reported that sorption of P was strongly correlated with the amounts of Al_o and Fe_o. In addition, Wang *et al.* (2001) mentioned that many soils with high P retention was related to high levels of oxalate extractable Fe and Al. The effect of Al_o on PBC occurring in the third model was not uncommon because the ammonium oxalate extraction was a selective solution for amorphous Fe and Al compounds.

Soil properties were substituted into models (2) and (3) to predict the PBC_{Bray-2} and PBC_{Pi-test}. The predicted PBC was plotted against

the observed PBC to study the predictability of the models (Figure 1).

The relationship in Figure 1A showed that the predicted PBC_{Bray-2} was higher than the observed PBC. The predicted PBC in model (3) were very close to the observed PBC, the points being distributed along with the 1: 1 line (Figure 1B), these illustrated that the Pi-test method was better than the other methods in predicting PBC of the selected soils.

CONCLUSIONS

Phosphorus buffer coefficient is one of the important variables in the PDSS program for P fertilizer requirement prediction. PBC of the eight selected soils differed with different methods of P extraction. The PBC_{Bray-2} were highest values and PBC_{Mehlich-1} were the lowest. The PBC_{Mehlich-1} were not correlated with soil properties studied, while PBC_{Bray-2} increased with decreasing percentage of clay content. Percentage of clay content and acid ammonium oxalate extractable aluminum were the main factors affecting the PBC_{Pi-test}. This study suggested that PBC_{Pi-test}

should be used for PBC estimation because the model was more accurate compared to PBC_{Bray-2}.

ACKNOWLEDGEMENTS

The authors would like to thank Ms. J. Chuenrung, Department of Agriculture for assistance in determination of field capacity moisture content of the selected soils. Thank are also to laboratory staffs of Department of Soil Science, Kasetsart University for assistance in soil analysis. We thank Ms. N. Hongthanat for her valuable suggestion on the iron oxide-impregnated filter paper method (Pi-test) during the experiment.

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