

Comparison of Laboratory pH Buffer Methods for Predicting Lime Requirement for Acidic Soils of Eastern Botswana

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ABSTRACT

The suitability of pH buffer methods that determine lime requirement (L.R.) of acid soils of the eastern region of Botswana has not been determined, and the soil physiochemical properties that influence L.R. are not known. As a result, a number of laboratory pH buffer methods for determining L.R. were evaluated by using acid soils from that region. The methods evaluated were the Yuan double buffer (Yuan–DB) method, Shoemaker, McLean, and Pratt double, and single buffer (SMP–DB and SMP–SB) methods, and the Adams, and Evans single buffer (AE–SB) method. The evaluation was based on the ability of the methods to predict the actual L.R. to pH 6.5 determined by the soil–CaCO₃–moist–incubation (SCMI)

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method. The incubation, physiochemical properties, and L.R. by laboratory pH buffer methods were determined in triplicates. All the pH buffer methods were ($P < 0.001$) significantly correlated ($0.79 < r < 0.94$) with the SCMI method. The performance was in the order of Yuan–DB method > SMP–DB method > SMP–SB method > AE–SB. However, the SMP–SB has been recommended for routine analysis of soils of eastern Botswana, because it is simple and rapid. The relationship between SCMI method actual L.R. and the physiochemical properties ($0.55 < r < 0.71$) reveals that the buffer capacity, organic carbon, exchangeable acidity, and extractable aluminum are the most important soil properties influencing L.R. of soils in eastern Botswana.

Key Words: Lime requirement; pH buffer methods; Soil pH; Buffer capacity.

INTRODUCTION

The lime requirement (L.R.) may be defined as the amount of lime required to raise the soil pH to a target value^[1] or the amount of lime required to remove limitations to crop growth.^[2] The L.R. depends on the soil pH buffer capacity (BC). The soil pH BC is a function of many soil properties. Aitken et al.^[3] reported that organic carbon, clay content, and exchangeable acidity accounted for 85% of the pH BC of Queensland soils in Australia. Owusu-Bennoah et al.^[4] reported that organic carbon and exchangeable aluminum were the two main properties that influenced L.R. of Ghanaian soils to pH 6.0.

Several laboratory methods have been developed to estimate L.R. of acid soils. Some of the buffer methods are Adams and Evans^[5] single buffer (AE–SB), Shoemaker et al.^[6] single buffer (SMP–SB), Yuan^[7] double buffer method (Yuan–DB), McLean et al.^[8] single buffer (SMP–DB), and the soil–CaCO₃–moist incubation (SCMI) method.^[9] These methods have their strengths and weaknesses. McLean et al.^[8] reported that the SMP–SB was accurate for soils that have a L.R. > 4 cmol kg⁻¹ soil, pH < 5.8, and organic matter < 10%. The L.R. values of the SMP–SB method are highly correlated with values of SCMI method.^[10] However, the SMP–SB overestimated the L.R. of sandy soils, was not accurate for muck soils, and became less sensitive as the target pH approaches 7.0.^[11] The AE–SB is sensitive on soils that have a cation exchange capacity (CEC) that ranges from 1–10 cmol/kg.^[11] McLean et al.^[12] and Yuan^[13] observed that the method underestimated the L.R.



of soils with a high CEC. The method also overestimated the L.R. of soils with a low L.R. and underestimated the L.R. of soils with a high L.R.^[14] The double-buffer methods were developed to overcome the weaknesses of the single-buffer methods, especially the SMP–SB method. The double-buffer methods take into consideration the acidity and the BC of individual soils. The SCMI method is the most accurate method among the L.R. methods. It simulates field liming and determines the actual L.R. As a result, it is used to calibrate other L.R. methods. However, the SCMI method is not used for routine analysis because the reaction between lime and the soil requires weeks and months to become complete.^[15] Researchers have incubated for 2 months^[16] and for 1 month.^[8] Information on L.R. for soils of eastern of Botswana is lacking. The buffer methods have not been evaluated on these soils. The objectives of this study are the following: (a) to compare the suitability of the buffer methods for determination of L.R. to a target pH of 6.5 for acid soils of the eastern Botswana, and (b) to determine the physio-chemical properties that influence the L.R. of these soils.

MATERIALS AND METHODS

Soils Used

A total of 22 representative acid soil samples from the eastern region of Botswana were used in the study. The soils were sampled from 22 cultivated fields to a depth of 15–20 cm after surface residue has been removed. A composite sample weighing 1 kg was collected from each field. The samples were air-dried and ground to pass through a 2-mm sieve.

Analytical Methods

The soil pH in water (pH_w) was determined in a 1:1 wt/vol soil–water suspension with a glass-electrode–equipped pH meter. To the suspension, 0.05 mL of CaCl_2 was added to determine soil pH in CaCl_2 (pH_S).^[17] The clay percentage was determined by the hydrometer method.^[18] Organic carbon was determined by Walkley and Black method.^[19] The BC of each soil was determined from the soil-moist incubations as the reciprocal of the slope of the regression line.^[1] The exchangeable basic cations [calcium



(Ca), magnesium (Mg), potassium (K), and sodium (Na)] were determined by the ammonium acetate method, and the exchangeable acidity was determined by the barium chloride–triethanolamine method.^[20] Exchangeable aluminum was determined by the potassium chloride method.^[21] The effective cation exchange capacity (ECEC) was determined by summing the exchangeable bases and exchangeable aluminum. The aluminum saturation was calculated as $Al / (Ca + K + Mg + Al) \times 100$.^[22] The base saturation was determined by subtracting the aluminum saturation from 100. All soil physiochemical properties were determined in triplicates.

Lime Requirement Methods

SCMI Method

Soil samples were thoroughly mixed with various levels of $CaCO_3$ corresponding to 0, 0.5, 1, 1.5, 3.5, 7.5, 9.5, 11.5, and 15 t/ha. The soil samples were incubated in triplicates. The mixtures were incubated at room temperature and at approximately field capacity for 1 month. After the incubation period, the mixtures were air-dried, and the pH was determined in a 1:1 wt/vol soil–water suspension. From the pH vs. lime-added curve, the L.R. to pH 6.5 was obtained, and the BC was determined as the reciprocal of the slope of the curve.

SMP–SB Method

The soil buffer equilibrium pH was determined in triplicates by equilibrating 10 mL of the buffer at pH 7.5 with a 1:1 wt/vol soil–water suspension for 30 min.^[17] The L.R. values were obtained from a table prepared by Shoemaker et al.^[6]

AE–SB Method

The soil-buffer equilibrium pH was determined in triplicates by equilibrating 20 mL of the buffer at pH 8 with a 1:1 wt/vol soil–water suspension. The L.R. values were obtained from table prepared by Adams and Evans.^[5]



SMP–DB Method

The soil-buffer equilibrium pH was determined in triplicates at initial pH values of 7.5 and 6, and the L.R. was determined by using formulas developed by McLean et al.^[8]

Yuan–DB Method

The soil-buffer equilibrium pH was determined in triplicates at initial pH values of 7.0 and 6 and the L.R. was determined by using formulas developed by Yuan.^[7]

Statistical Analysis

Simple linear correlation and regression techniques were used to evaluate the methods.^[23]

RESULTS AND DISCUSSION

The soils had a suitable range of soil properties for the determination of L.R. Soil pH_S ranged from 0.22 to 6.30 and the pH BC ranged from 0.22 to .61 $\text{cmol CaCO}_3 \text{ kg}^{-1}$ soil unit⁻¹ (Table 1). The percentage clay exhibited a wide range of values from 1.4 to 53%. Organic carbon was in the range of 0.11 to 0.61%, and exchangeable aluminum was in the range of 0.12 to 41 cmol kg^{-1} soil. The CEC and exchangeable acidity were in the ranges of 0.90 to 3.35 cmol kg^{-1} soil and 0.89 to 1.65 cmol kg^{-1} soil, respectively. The soils used in the study had L.R. that ranged from 0.70–3.25 $\text{g CaCO}_3 \text{ kg}^{-1}$ soil determined by the SCMI method (Table 2). These different ranges and averages indicate variations in L.R. from soil to soil and from method to method (Table 2).

The AE–SB method (Fig. 1a) produced correlation coefficient ($r=0.56$) and the standard error of the estimate ($SE_b=0.33$). The AE–SB was not highly significantly correlated ($P<0.001$) with the actual L.R. The soils used in this study had no properties for which the AE–SB was created. Close examination also indicates that the AE–SB method tends to underestimate L.R. of those soils with a low L.R. and underestimate the L.R. of those soils with a high L.R. (Fig. 1a). There is an uneven distribution of data points along the regression line and a



Table 1. Physiochemical properties of the soils used in the study.

Location	Soil classification	pH			Clay (%)	OC (%)	cmol/kg					Exch. acidity	Extr Al	Base sat. (%)	Al sat. (%)	
		H ₂ O	CaCl ₂	BC			Ca	Mg	K	Na	Al					ECEC
Dibete 1	Typic ustropepts	4.3	4.2	0.4	2.0	0.3	0.2	0.2	0.1	0.1	0.3	0.9	1.5	2.4	71	29
Dibete2	Typic ustropepts	5.4	5.3	0.5	2.0	0.3	0.2	0.1	0.3	0.1	0.2	1.2	1.4	2.5	57	43
Gaborone	Oxic haplustalfs	5.3	4.7	0.5	33.0	0.2	0.4	0.3	0.1	0.1	0.3	1.1	1.4	3.3	78	22
Gakale	Vertic ustochrepts	6.0	5.0	0.3	38.0	0.2	0.7	0.1	0.1	0.1	0.3	1.3	1.3	3.8	76	24
Lobatse 1	Typic haplustalfs	4.7	4.4	0.5	15.0	0.6	0.5	0.4	0.4	0.3	0.5	2.1	1.6	5.3	76	24
Lobatse 2	Kandic paleustalfs	6.2	4.9	0.5	18.0	0.5	0.6	0.4	0.4	0.1	0.5	2.0	1.5	3.2	77	23
Mabalane	Vertic ustochrepts	5.0	4.6	2.8	53.0	0.4	0.6	0.3	0.5	0.2	0.7	2.3	1.3	4.3	70	30
Mahalapye	Aridic haplustalfs	4.9	4.2	0.4	7.6	0.2	0.6	0.5	0.3	0.1	0.4	2.0	1.2	2.9	78	22
Makoro 1	Aridic haplustalfs	5.5	4.4	0.7	11.3	0.6	0.8	0.5	0.1	0.1	0.5	1.9	1.6	5.9	76	24
Makoro 2	Aridic haplustalf	4.7	4.4	0.5	18.5	0.4	0.8	0.4	0.2	0.1	0.4	1.8	1.5	4	77	23
Makwatwe 1	Aridic haplustalfs	5.4	5.3	0.3	12.1	0.1	0.7	0.5	0.4	0.1	0.5	2.1	1.1	1.4	79	21
Makwate 2	Aridic haplustalf	5.8	5.6	0.2	16.2	0.2	0.6	0.4	0.4	0.1	0.4	2.0	0.9	1.3	79	22
Makwate 3	Kandic paleustalfs	5.5	4.5	0.5	8.0	0.5	0.5	0.3	0.4	0.1	0.7	2.1	1.5	3.3	65	35
Mathubudukwane	Typic rhodustalfs	6.5	5.9	0.4	20.0	0.2	0.8	0.6	0.4	0.4	0.9	3.1	1.2	3.2	72	28

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Metsemaswaana	Ultic haplustalfts	4.9	4.3	0.6	10.0	0.4	0.7	0.4	0.2	0.1	0.6	2.0	1.6	5.1	69	31
Modipane 1	Kanhaplic haplustalfts	6.5	5.2	0.5	12.0	0.4	0.9	0.6	0.2	0.1	0.6	2.4	1.5	3.5	76	24
Modipane 2	Kanhaplic haplustalfts	5.7	5.0	0.6	30.0	0.4	0.8	0.4	0.2	0.1	0.5	2.0	1.6	4.5	76	24
Ootse 1	Oxic paleustalfts	5.7	4.5	0.5	8.0	0.5	0.5	0.2	0.3	0.3	0.4	1.7	1.5	4.9	79	21
Ootse 2	Oxic paleustalfts	5.5	4.7	0.6	8.0	0.4	0.7	0.4	0.4	0.3	0.5	2.3	1.4	4.8	78	22
Ramonaka	Typic ustropepts	6.6	6.3	0.4	52.0	0.4	0.6	0.4	0.3	0.3	0.4	2.0	1.7	3.4	78	22
Taung	Fluentic eutrochrepts	5.7	5.2	0.6	47.0	0.5	0.8	0.5	0.1	0.1	0.6	2.2	1.4	4.5	71	29
Sebele	Typic haplustalfts	5.6	5.35	0.3	1.4	0.1	0.8	0.4	0.2	0.10	0.5	2.0	1.2	1.9	76	24
Mean		5.5	4.9	0.6	19.2	0.4	0.6	0.4	0.3	0.1	0.5	1.9	1.4	3.6	75	25



Table 2. Lime requirement of soils determined by five methods used in the study.

Location	Lime requirement (g CaCO ₃ kg ⁻¹ soil)				
	SMI	Yuan-DB	SMP-DB	SMP-SB	AE-SB
Makwate 2	0.7	0.9	1.2	2.7	1.4
Makwate 1	1.0	1.0	1.7	2.7	1.8
Mahalapye	1.1	1.1	1.5	2.7	2.4
Sebele	1.3	1.3	1.8	2.7	1.6
Mathubudukwane	1.3	1.8	1.8	2.7	0.5
Gakale	1.3	1.8	1.5	2.7	1.2
Dibete 2	1.4	1.5	1.9	2.7	1.8
Gaborone	1.5	2.1	1.5	4.7	1.8
Dibete 1	1.6	1.7	1.7	4.7	2.4
Makoro 2	1.6	1.9	1.8	4.7	2.3
Makwate 3	1.8	2.2	1.6	5.3	0.9
Taung	1.9	2.4	2.0	6.5	0.5
Ramonaka	2.3	2.5	2.9	6.5	1.5
Lobatse 2	2.4	2.8	2.6	6.5	4.3
Ootse 1	2.5	2.7	2.8	6.5	4.9
Modipane 1	2.5	2.8	2.8	6.5	1.0
Mabalane	2.8	3.3	3.3	8.5	4.2
Ootse 2	2.8	3.3	3.3	12.3	4.8
Modipane 2	3.0	3.0	3.2	6.5	3.5
Lobatse 1	3.1	3.0	3.2	8.5	4.8
Metsemaswaana	3.2	3.5	3.0	10.5	4.2
Makoro 1	3.3	3.6	3.8	12.3	6.7
Means	2.0	2.3	2.3	5.9	2.7

relatively considerable deviation from the line, indicating low precision of prediction by the AE-SB method.

The SMP-SB method had a high correlation coefficient ($r=0.80$), the $SE_b=0.37$ was relatively large (Fig. 1b). This indicates a decreased predictability by using the method.

The SMP-DB and Yuan-DB L.R. estimates were highly correlated with the actual L.R. (Figs. 1c, d). Similar results were obtained by Aitken et al.^[24] The double buffers, performed better than the single buffers, because they were developed as an improvement of the single buffers and they also account for the buffering capacity of individual soils. The performance of the buffer methods were in the order of Yuan-DB > SMP-DB > SMP-SB > AE-SB.



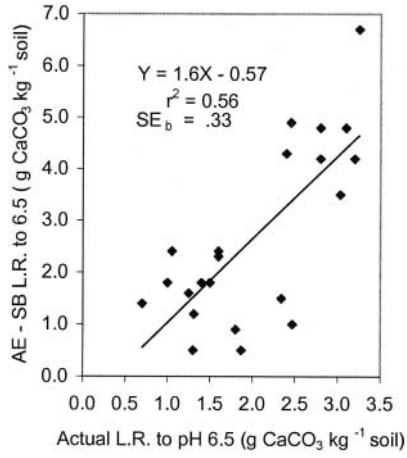


Figure 1a. Relationship between AE-SB lime requirement and actual lime requirement values to pH 6.5.

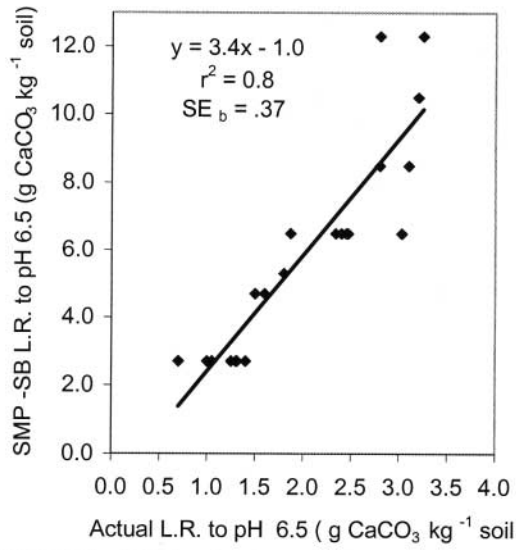


Figure 1b. Relationship between SMP-SB lime requirement and actual lime requirement values to pH 6.5.



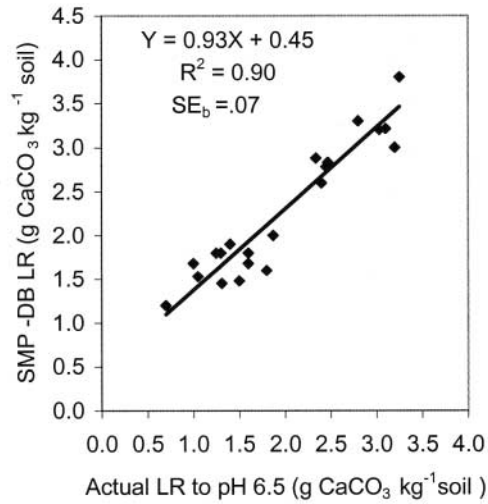


Figure 1c. Relationship between SMP–SB lime requirement and actual lime requirement values to pH 6.5.

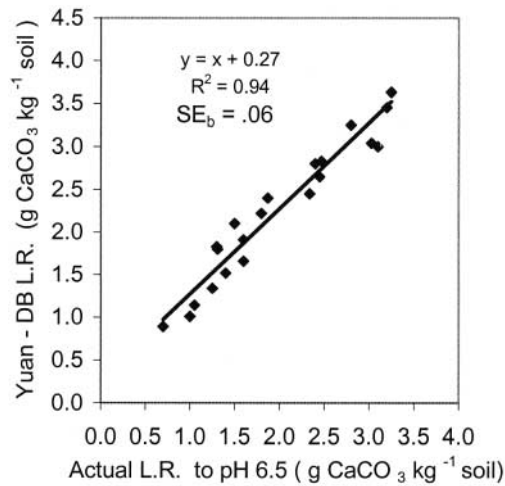


Figure 1d. Relationship between Yuan–DB lime requirement and actual lime requirement values to pH 6.5.



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Table 3. Regression equations, correlation coefficients, and standard error of the estimate between soil physiochemical (*X*) and the actual lime requirement (*Y*).

Property	Regression equation	Correlation coefficient (<i>r</i>)	Standard error of estimate (<i>SE_b</i>)
pH (H ₂ O)	$Y = 0.041X + 2.24$	0.1 ^{NS}	0.29
pH (CaCl ₂)	$Y = 4.29 - 0.47X$	0.11 ^{NS}	0.30
Buffer capacity	$Y = 0.06X + 4.53$	0.54 ^a	0.95
Organic carbon (%)	$Y = 4.45X + 0.47$	0.70 ^b	0.66
Clay (%)	$Y = 1.88 + 0.01$	0.20 ^{NS}	0.01
Exch. Al (cmol/kg)	$Y = 1.12X + 1.47$	0.52 ^a	1.1
ECEC (cmol/kg)	$Y = 1.43 + 0.31$	0.33 ^{NS}	0.37
Exch. acidity (cmol/kg)	$Y = 3.36X - 2.70$	0.62 ^b	0.83
Extra. Al (cmol/kg)	$Y = 0.054 + 0.54X$	0.71 ^b	0.29

^{NS}Nonsignificant.

^aSignificant at $P < 0.05$.

^bSignificant at $P < 0.001$.

The pH_w and pH_S were not significantly correlated with the actual L.R. (Table 3). The poor correlation is a result of the fact that pH measures the intensity of the H⁺, while L.R. is influenced by the initial soil pH BC. Similar results were obtained by Aitken et al.^[24] and Dolui and Saha.^[9] The CEC and, the clay percentage were also not significantly correlated with the actual L.R. This finding was consistent with those found by Patiram and Prasad.^[25] It was noted that the soil pH BC was significantly ($r = 0.74$) correlated with the actual L.R. This was expected, because L.R. is dependent on the soil pH buffer capacity and the initial pH. The findings were similar to those obtained by Aitken et al.^[24] The actual L.R., organic matter, and extractable aluminum were significantly ($P < 0.001$) related with correlation coefficients of $r = 0.70$ and 0.71 , respectively. The reason for a good correlation might be that aluminum is the principal component of exchangeable acidity. The good relationship between the actual L.R. and organic carbon was also expected because the H⁺ produced by the dissociation of the hydroxyl and carboxyl groups influences L.R. Similar results were reported by De Souza et al.^[26]

In conclusion, all buffer methods performed well with regard to estimating L.R. The Yuan–DB appears to be the most precise method for estimating L.R. for soils of the eastern Botswana. However the Yuan–DB has not been recommended for routine analysis because of its complexity, instead the SMP–SB buffer is recommended because of its simplicity and speed.



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