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Research article

Evaluation of lime requirement estimation methods for acid soil management and yield of bread wheat (*Triticum aestivum* L.) in Wadla District of North Wollo Zone of Amhara Region

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A field study was conducted to determine the lime requirement (LR) by using different methods and investigate wheat response to lime and phosphorus fertilizer. Shoemaker-McLean-Pratt (SMP) buffer, $Ca(OH)_2$ titration, permissible acid saturation percentage (PASP) and exchangeable acidity LR testing methods were evaluated with factorial combination of P; 0, 34.5 and 69 kg P_2O_5 ha^{-1}, arranged in a randomized complete block design with three replications. The result showed that there was significant ($p \leq 0.05$) yield response to the main effect of liming at the testing site where the soil pH was 5.14, while there was no significant yield response to liming at those testing sites where the soil pH varied from 5.25 to 5.60. The highest grain yield of 3.61 t ha^{-1} was obtained from lime treated with $Ca(OH)_2$ titration method statistically at par with SMP buffer method. Similarly, the yield of wheat was significantly affected by the main effect of application of P at two testing sites. The highest grain yields of 3.66 t ha^{-1} statistically at par with 3.49 t ha^{-1} were obtained from application of 46 and 23 kg P_2O_5 ha^{-1}, respectively. SMP method estimated lime raised the soil pH from 5.8 to 6.5, 6.2 to 6.9 and 5.8 to 6.2, while $Ca(OH)_2$ titration method estimated lime raised soil pH from 5.8 to 6.3, 6.2 to 6.7 and 5.8 to 6.1. However, the LR estimated with $Ca(OH)_2$ titration method was lower from the LR estimated with SMP method by an average of 37.6%, which indicates SMP buffer method overestimated the LR for the present study area, while the PASP and exchangeable acidity methods were found to underestimate the LR. Thus, $Ca(OH)_2$ titration method was found the best LR estimation method among the methods evaluated in this study.

Key words: liming, lime requirement, soil acidity, Wadla, wheat

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INTRODUCTION

Soil acidity is one of the major problems that limit agricultural productivity in the mid and highlands of Ethiopia (Taye, 2007). According to Schlede, 1989, it covers 41% of the land in Ethiopia. Out of the 41%, 28% is moderately acidic (pH 4.5-5.5) and 13% is strongly acidic (pH < 4.5). Soil acidification and soil erosion are the major soil degradation issues in the humid and highlands areas of North Wollo Zone of the Amhara Region. Different studies have shown that soils in the highland areas of North Wollo including the present study area, Wadla district, have become acidic ranging from moderately to slightly acidic.

High levels of soil acidity can cause reduction of root growth, nutrient availability, affect crop protectant activity reduction and total failure of crop yields and deterioration of soil physical properties (Prassad and Power, 1997). In general it affects the biological, chemical and physical properties of soil, which in turn affect the sustainability of crop production in both managed and natural ecosystem.

Thus, amendments and maintenance of soil acidity is a very important soil management for crop production. Lime is the major means of ameliorating soil acidy (Anetor *et. al.,* 2007). Because it has very strong acid neutralizing capacity, which can effectively remove existing acid. Liming increases the uptake of nutrients, stimulate biological activity and reduce toxicity of Al and Mn.

Lime requirement (LR) is the amount of liming material that must be applied to a soil to raise its pH from an initial acid condition to a level selected for near-optimum plant growth (McLean *et. al.*, 1978). Thus, to reclaim the soil acidity problems in North Wollo Zone, the North Wollo Zone Bureau of Agriculture with Dessie Regional Soil Testing Laboratory had conducted extensive soil acidity assessment survey and had advised different LR recommendations on farmer's field level. However, the LR testing method, permissible acid saturation percentage method (PASP) as described by Taye *et. al.* (2007 unpublished), which had been used to determine the LR was reported to underestimate the optimum lime rate required. Some soil testing laboratories in the region have later adopted SMP single buffer method (Shoemaker *et al.*, 1961) for LR determination.

Different rapid LR testing methods can give widely divergent results (Peech, 1965). Certain methods are better suited to specific soil conditions (Mehlich *et. al.,* 1976). Many qualitative and quantitative methods have been used to estimate the LR including $CaCO_3$ incubations, titration techniques, buffer methods, determination of exchangeable aluminum, and indirect LR determination methods.

Lime requirement estimation with buffer methods are indirect lime estimation methods developed based on calibration/regression experiments with the widely accepted LR determination method i.e., soil incubation with $CaCO_3$/$Ca(OH)_2$ under green house. However, LR is affected by a soil's pH and its buffering capacity, which is determined by soil texture, type of clay minerals, and the amount of organic matter (Magdoff *et al.,* 1987). Therefore, they need to be calibrated and validated for Ethiopian soil as most of the buffer methods were developed in US for American soils. Discrepancies in the literature exist about what is the most appropriate method to determine the actual LR of an acid soil. In addition, the level of accuracy of LR testing methods in neutralizing the soil acidity to the desired level needs to be tested and validated on the field conditions.

On the other hand, highly weathered tropical and acid soils have strong P sorption capacities which intensify limitation of land suitability. Phosphorus (P) fixation by the predominant Al^{3+} and Fe^{2+} ions in a strong acid soil conditions leads to P deficiency. Therefore, lime application needs to be integrated with P fertilizer supply in order to achieve maximum crop yields in acid soils. This study was, therefore, proposed with the objectives of selecting the most appropriate and relatively accurate LR determination methods suitable for the study area and evaluating the yield response of wheat to the combined application of lime and P fertilizer.

MATERIALS AND METHODS

Site Description

The study was conducted in 2014-2015 and 2015-2016 main cropping seasons in Wadla district of North Wollo zone of the Amhara Region. The study district is situated with an altitude range of 2000-2800 meters above sea level and within the geographical coordinates of 11° 49'59.99" N and 38°49'59.99" E. The district receives a mean annual rainfall of 800-1200 mm with minimum and maximum temperature of 17 and 22°C, respectively.

Experimental Procedures

Selection of farmers' fields and lime estimation methods

Soil samples at a depth of 0-20 cm were collected from ten farmers' fields prior to starting the experiment for pH analysis. Based on the soil pH (1:2.5 soil:water suspension), four farmers' fields with strong to slight soil acidity were selected for the experiment. Four different methods were used for the determination of LR such as, SMP single buffer method (Shoemaker *et al.*, 1961), $Ca(OH)_2$ direct titration method (Dunn, 1943**;** Liu *et al.*, 2004), permissible acid saturation percentage method-PASP (Manson and Katusic, 1997) and exchangeable acidity method (multiplied by a correction factor of 1.5 and it is included in the second year of the study).

Soil testing procedures for LR estimation methods

Shoemaker-McLean-Pratt (SMP) single buffer (SB) method

Ten milliliter of SMP buffer (pH 7.5) was added to the soil-water slurry used for pH determination (1:1 soil water suspension), then, the mixture was closed tightly and shaken at 250 excursions per minute for 10 minutes and was settled for 20 minutes. The pH was measured under stirring to the nearest 0.01 pH unit. Finally, the lime requirement was determined from soil-buffer pH and existing calibrated data developed in US.

$Ca(OH)_2$ direct titration method (Dunn, 1943; Liu et. al., 2004)

Thirty milliliter distilled water was added to 30 g of air dried and ground soil sample, which passed through a 2 mm sieve. The water soil mixture (ratio of 1:1) was carefully mixed with a glass rod for 30 minutes and left to decant for 30 min. The initial soil pH was measured under stirring by inserting a pH electrode in to the water soil mixture. Since titration curves are nearly linear within the pH range of most agricultural surface soils (4.5 to 6.5), three aliquots of base ($Ca(OH)_2$) were used to develop the slopes of the titration curves for each soil. Thus, three time of 3 ml of $Ca(OH)_2$ solution (0.022M) were added to the above mixture with 30 minutes interval every time while mixing thoroughly for 30 min for each addition.. The changes in pH were measured systematically. The pH electrode was rinsed with distilled water after each pH measurement to avoid cross contamination.

The titration curve was plotted by taking the pH values (4 pH values including the initial pH measurement) measured against the volume of $Ca(OH)_2$ added. A linear regression graph was then fitted by plotting the base added in the abscissa and the change in soil pH measured in the ordinate. Then, the LR was calculated based on the slopes of the linear regression equations and the pH difference between initial pH (y intercept) and the desired pH i.e. 6.5 as shown in the equation below;

$$\text{LR (kg CaCO3 per ha)} = \frac{6.5 - \text{Intercept}}{\text{Slope}}$$

Permissible acid saturation percentage method (PASP) (Manson and Katusic, 1997)

$\text{LR (kg CaCO3 per ha)} = 1160 \text{ x } \left[\text{Exchangeable acidity} - \frac{1}{10}(\text{ECEC})\right]$. Where, ECEC is effective cation exchange capacity and 1/10 (ECEC) is meant for the assumption that the permissible acid saturation percentage level for wheat is 10% (1/10).

Exchangeable acidity method

$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\,m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000} * 1.5$. Where, EA is exchangeable acidity, B.D is soil bulk density and a 1.5 multiplication factor was adopted based on a recommendation by Birhanu et. al. (2016).

Liming, fertilizer applications and planting

In the field evaluation study, the LRs determined with the four lime testing methods and control (without lime) were factorially combined with three levels of P fertilizer (0, half and full of the recommended P i.e. 46 kg P_2O_5 ha^{-1}). The treatments were arranged in a randomized complete block design with three replications.

Agricultural calcitic lime with fineness factor of 0.52, moisture content of 1.06%, and Calcium Carbonate Equivalent (CCE) of 90% (Mekonen et. al., 2014) produced from Dejen lime factory was spread evenly and incorporated in to the plow layer (20 cm) three weeks before planting the test crop. Phosphorus fertilizer was applied in a row all at planting. While, N fertilizer (69 kg N ha^{-1}) was applied half at planting and the remaining half at tillering (40 days after planting).

The plot sizes had an area of 12 m2 (3 m * 4 m) with a spacing of 1 m between experimental plots and replications. The bread wheat variety with local name *Sora* was used, planted by drilling in a row with 20 cm spacing and a seeding rate of 150 kg ha-1. There was a total of 20 rows of plants in each plot out of which the inner most 18 rows were harvested and used for data collection and analysis.

Soil Sampling

Four composite surface (0-20 cm) soil samples were collected from the four farmers' fields before application of lime for analysis of pH (H_2O and 0.01 M $CaCl_2$), texture, exchangeable acidity, exchangeable aluminum, available P, exchangeable Ca, Mg, K and Na. Surface (0-20 cm). Surface soil samples (0-20 cm depth) were also collected plot wise after harvesting for analysis soil pH, exchangeable acidity and exchangeable Al^{3+}.

Soil Analysis

Particle size distribution (soil texture) was determined following the modified Bouyoucos hydrometer method (Bouyoucos, 1962). Soil textural class names were then assigned based on the relative contents of the percent sand, silt, and clay separates using the soil textural triangle of the USDA. Soil pH was measured potentiometrically using a combined glass electrode pH meter in water and 0.01M $CaCl_2$ solution at 1:2.5 soil to water ratio (Van Reeuwijk, 1992). Exchangeable acidity was determined by saturating the soil samples with 1M KCl solution and titrating with 0.01M NaOH as described by Mclean (1965) and Rowell (1994). Exchangeable Al was determined from aqueous solutions extracted by 1M KCl and NaF and titrated with 0.01M HCl. Exchangeable bases (Ca, Mg, Na and K) were extracted with 1M NH_4OAc at pH 7 and then Ca and Mg were determined by EDTA titration, while K and Na were determined using flame photometry. Effective cation exchange capacity was calculated as the sum of exchangeable basic cations and exchangeable acidity (United States Department of Agriculture Soil Survey Information Laboratory Manual, 1995). While, organic carbon (OC) was determined by wet digestion method through chromic acid digestion method as described by Walkley and Black (1934) and available P was determined colorimetrically using Olsen's method (Olsen, 1952).

Data collected

Grain yield was measured at maturity from the inner most 18 rows and was adjusted to a 12.5% moisture content. Fresh biomass weight was measured by weighing the fresh total above ground biomass of the harvested rows. While, the dry biomass weight was measured by taking straw sample with the seed spikes, drying in an oven at 105 °C for 12 hours and adjusting the fresh biomass weight in to dry basis by using the moisture content measured after an oven dry. Plant height was measured at maturity from random five plant samples of the harvestable rows, from ground level to the tip of the spike including the awns. Thousand seed weight was also measured by weighing 1000 random seeds on a sensitive balance.

Data analysis

The data recorded were subjected to analysis of variance (GLM procedure) using SAS software version 9.00 (SAS Institute, 2004). The LSD and DMRT mean separation methods at 5% probability level were used to separate treatment means. Statistical analysis result of plant height and 1000 seed weight data are not included in the report as grain and dry matter yield can show the effect of liming and application of P with better magnitude.

Results and Discussion

Soil Acidity and Some Soil Physico-chemical Properties of Study Sites before Liming

The soil acidity levels and some other physico-chemical properties of surface soils (0-20 cm) of the four experimental farmers' fields in the two experimental years before liming is shown in the table below (Table 1 and 2). Based on the ratings by Jones (2003), the soils of two testing sites in the first experimental year were strongly acidic (Table 1). While, acidity levels of the testing sites selected in the second experimental year vary from strongly to moderately acidic (Table 2).

Table 1. Acidity levels and some physico-chemical properties of surface soils (0-20 cm) of the study fields in the first experimental year (2014)

Testing Site	pH (H_2O)	pH ($CaCl_2$)	Exch. H	Exch. Al	Exch. acidity	Percent acid saturation (%)
			meq/100 g			
Site 1	5.14	4.43	0.380	0.65	1.024	12.70
Site 2	5.51	4.63	0.128	-	0.128	2.10

Testing Site	Exch. Ca+Mg	Exch. Na	Exch. K	ECEC*	Sand	Silt	Clay	Textural Class
	meq/100				%			
Site 1	6.55	0.195	0.269	8.0381	24	48	28	Clay loam
Site 2	5.55	0.130	0.256	6.0642	26	48	26	Clay

*ECEC=Effective Cation Exchange Capacity.

Table 2. Acidity levels and some physico-chemical properties of surface soils (0-20 cm) of the study fields in the second experimental year (2015)

Testing Site	Exch. Ca+Mg	Exch. Na	Exch. K	ECEC*	Sand	Silt	Clay	Textural Class
	meq/100					%		
Site 1	6.55	0.195	0.269	8.0381	24	48	28	Clay loam
Site 2	5.55	0.130	0.256	6.0642	26	48	26	Clay

*ECEC=Effective Cation Exchange Capacity.

LR estimated based on the four testing methods

The LR predictions for the study farmers' fields based on the three (first year) and four (second year) LR testing methods such as SMP buffer method, $Ca(OH)_2$ direct titration method, PASP method and exchangeable acidity method (added in the second experimental year) are shown in the tables below (Table 3 and 4).

Table 3. LR ($CaCO_3$ t ha^{-1}) of the study fields based on the three LR testing methods in 2014

Testing sites	SMP buffer	$Ca(OH)_2$ titration	PASP
Site 1	13.4	8.8	0.3
Site 2	9.8	5.0	NL
Mean	11.6	6.9	0.3

NL: No lime is required based on prediction of the method

Table 4. LR ($CaCO_3$ t ha^{-1}) of the study fields based on the four LR testing methods in 2015

Testing sites	SMP buffer	$Ca(OH)_2$ titration	Exchangeable acidity	PASP
Site 3	3.30	2.22	0.32	NL
Site 4	1.20	1.26	0.20	NL
Mean	2.25	1.74	0.26	NL

NL: No lime is required based on prediction of the method

Effect of Application of Lime and P Fertilizer on the Wheat Yields

The first year result indicated that the main effects of application of lime rates determined with three different lime estimation methods had significant ($P \leq 0.05$) effect on the yield of wheat at site 1 (Table 5). However, the yield of wheat at site 1 was not significantly affected by application of P fertilizer. This might be due to the relatively better soil fertility status of the soil as this testing site was close to a homestead. The yield response to the application of lime at site 1 was most likely attributable to raise in the soil pH and elimination of the possibility of exchangeable Al^{3+} toxicity as the level of Al^{3+} was reduced from 0.65 meq/100 g to 0 meq/100 due to liming. This result is supported by Lamond and David (1995), Okalebo *et.al.,* 2002 and Osundw *et. al.* (2013) who reported that application of lime significantly improved the productivity of wheat on acidic soils. Similarly, Kettering (2005) reported that the increase in the agronomic yields due to liming might be attributed to the increases in soil pH, reduction in the ion toxicity of H or Mn and reduction in nutrient deficiency (Ca, P, or Mo) as well as due to indirect effect of better physical condition of the soil.

At testing site 2, there was a significant yield response to the application of P fertilizer (Table 5), which might be accounted for the low soil fertility status and P limitations to crop growth in the study district (World Bank, 1983; FAO, 1986). However, the yield of wheat was not significantly ($P>0.05$) affected by application of lime at site 2. This which might be due to the less adverse effect of the soil acidity level (pH 5.51) of the testing site on the yield of wheat as wheat is reported to be tolerant to the pH level 5.2 (Mahler and McDole, 1987).

Table 5. Main effects of application of lime rates ($CaCO_3$ t ha^{-1}) and P fertilizer rates (P_2O_5 kg ha^{-1}) on the wheat yields (kg ha^{-1}) at site 1 and 2 and pooled over sites in 2014

	Site 1			Site 2		Combined	
Lime* rates	Grain yield	Dry biomass	Lime* Rates	Grain yield	Dry biomass	Grain yield	Dry biomass
Control (0)	3596.2b	9328.7b	0	3872.9	10014.2	3734.6bc	9744.5ab
SMP (13.4)	4252.5a	10821.8a	9.8	4063.7	9791.7	4158.1a	10306.7a
$CaOH_2$ (8.8)	4058.9a	10439.3a	5.0	3877.9	9572.6	3968.4ab	10013.4ab
PASP (0.3)	3585.1b	9434.9b	-	-	-	3585.1c	9434.9b
Mean	3881.4	10019.3	Mean	3938.2	9792.9	3906.1	9937.0
CV (%)	9.4	8.7	CV (%)	7.5	9.9	9.7	8.3
LSD (5%)	365.0	902.5	LSD (5%)	Ns	ns	292.9	652.4
P rates*			P rates*				
Control (0)	3703.5	9489.8b	0	3782.2b	9373.2b	3737.2b	9482.6b
23	3945.5	10240.7ab	23	3788.4b	9375.0b	3874.8ab	9856.0b
46	4000.6	10395.6a	46	4243.9a	10584.0a	4104.9a	10487.1a
Mean	3881.4	10019.3	Mean	3938.2	9792.9	3906.1	9937.0
CV (%)	9.4	8.7	CV (%)	7.5	9.9	9.7	8.3
LSD (5%)	ns	782.7	LSD (5%)	297	989.9	238.7	536.6
P * Site	-	-	P * Site	-	-	ns	Ns
Lime * Site	-	-	Lime*Sit	-	-	ns	Ns

*Means with in a column followed by the same letter are not significantly different at 5% probability level.

NS: Non-significant at 5% probability level.

As shown in the above table (Table 5), at site 1, the highest grain (4.25 t ha^{-1}) and dry biomass (10.8 t ha^{-1}) yields were obtained from application of lime rate determined with SMP buffer method followed with insignificant difference by the grain (4.05 t ha^{-1}) and dry biomass (10.4 t ha^{-1}) yields obtained from application lime determined with $Ca(OH)_2$ titration method. Application of lime rates determined with the above two lime testing methods gave yield advantages of 18 and 12.9%, respectively over the non limed treatment. However, there was no significant yield improvement due to the application of lime determined with PASP, which was due to the lowest LR prediction by PASP method.

The combined analysis of wheat yield from the two testing sites showed a statistically significant effect of both the main effects lime and P fertilizer on the yields of wheat. The highest yield was obtained from application of lime rate determined with SMP buffer method followed with insignificant difference by the yield obtained from application of lime determined with $Ca(OH)_2$ titration method (Table 5).

The second year result from both testing sites showed that there was no significant difference in the yields of wheat due to the main and interaction effects of application of lime and P fertilizer (Table 6). This might be accounted for the less adverse effect of the soil acidity level of the testing sites on the growth of wheat as the surface soil pH level of the testing sites was in the range of 5.25 to 5.60 (Table 2). The pooled analysis over the two testing sites also revealed that there was no significant difference in grain and dry biomass yields due to the main and interaction effects of lime rates and P fertilizer rates (Table 6).

Table 6. Main effects of application of lime rates ($CaCO_3$ t ha^{-1}) and P fertilizer rates (P_2O_5 kg ha^{-1}) on the yields of wheat (kg ha^{-1}) at site 3 and 4 and pooled over sites in 2015

	Site 3		Site 4		Combined	
Lime* rates	Grain yield	Lime* Rates	Grain Yield	Dry biomass	Grain yield	Dry biomass
Control (0)	4021.8	0.00	1918.6	4127.4	2972.9	7251.7
SMP (3.30)	4141.6	1.20	1960.6	3985.9	3015.4	7108.3
$CaOH_2$ (2.22)	3913.8	1.26	2095.1	4303.7	2999.6	7242.2
Exch. acid. (0.32)	4310.7	0.20	2020.7	3963.7	3109.6	6986.0
Mean	4096.9	Mean	1999.3	4100.3	3024.35	7147.1
CV (%)	8.9	CV (%)	13.3	10.3	18.2	15.3
LSD (5%)	Ns	LSD (5%)	Ns	ns	ns	ns
P rates*		P rates*				
Control (0)	3950.4b	0	2075.7	4118.8	2968.3	6830.8
23	3965.8b	23	1930.1	4105.5	2908.2	7161.0
46	4374.6a	46	1992.5	4074.3	3196.6	7449.4
Mean	4096.9	Mean	1999.3	4100.3	3024.4	7147.1
CV (%)	8.9	CV (%)	13.3	10.3	18.2	15.3
LSD (5%)	311.4	LSD (5%)	Ns	ns	ns	ns

*Means with in a column followed by the same letter are not significantly different at 5% probability level.

NS: Non-significant at 5% probability level.

However, the pooled analysis of the agronomic data collected over all testing sites and experimental years revealed that the grain and dry biomass yields of wheat were affected by the main effects of both lime and P fertilizer (Table 7). The highest grain and dry biomass yields were obtained from the lime rates determined by SMP buffer method followed with insignificant ($P>0.05$) difference by the yield obtained from $Ca(OH)_2$ titration method. However, the average lime rate i.e., 4.32 t ha^{-1} $CaCO_3$ estimated with $Ca(OH)_2$ titration method was by 37.6% lower than the average lime rate i.e., 6.93 t $CaCO_3$ ha^{-1} estimated with SMP buffer method. Similarly, with regard to the yield response to applied P, the highest grain and dry biomass yield was obtained from application of 46 kg P_2O_5 ha^{-1} followed with insignificant yield difference from application of 23 kg P_2O_5 ha^{-1} (Table 7).

Table 7. Main effect of lime rates ($CaCO_3$ t ha^{-1}) and P fertilizer rates (kg P_2O_5 ha^{-1}) on the yields of wheat pooled over testing sites and experimental years

Lime rates*	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})	Plant height (cm)
Control (0)	3359.2b	8457.7	97.2
SMP buffer (6.93)	3580.5a	8685.9	98.3
$CaOH_2$ titration (4.32)	3614.9a	8733.8	97.6
Mean	3517.3	8625.2	97.7
CV (%)	11.47	9.5	2.8
LSD (5%)	190.67	Ns	ns
P rates*			
0	3393.5b	8227.9b	96.5b
23	3498.4ab	8715.2a	98.0a

Table 7. Continues

46	3659.4a	8948.9a	98.6a
Mean	3517.3	8625.2	97.7
CV (%)	11.47	9.50	2.80
LSD (5%)	190.67	392.34	1.27
Method*Site*Year	Ns	Ns	ns
P*Site*Year	Ns	Ns	ns

*Means with in a column followed by the same letter are not significantly different at 5% probability level.

NS: Non-significant at 5% probability level.

Effect of lime application on soil acidity

The soil analysis result of the surface soil samples collected at harvesting in both experimental years showed that application of LR estimated with SMP buffer and $Ca(OH)_2$ titration methods raised the soil pH significantly to the level optimum for wheat growth (Table 8 and 9). However, application of LR determined with PASP and exchangeable acidity methods did not significantly raise the soil pH as compared to the pH measured from the control treatment. Thus, PASP and exchangeable acidity methods were found to underestimate the LR.

The exchangeable acidity and exchangeable Al^{3+} measured from the soil samples collected at harvesting was zero due to the significant rise in the soil pH >5.5 as a result of liming. The increase in the soil pH measured at harvesting from the control treatment plot as compared to the initial pH measured before planting might be due to the dynamic property of soil pH which was raised as a result of the dry season period during harvesting (Olojugba and Fatubarin, 2015). On top of that, despite the lime was spread by broadcasting with much care to the lime treatment plots, due to its fineness, there was a possibility of movement of dusts of lime to the control plots by wind. This might also lead to elevated soil pH of the control plot measured at harvesting.

The raise in the surface soil pHs measured at harvesting due to the application of LRs determined with SMP buffer and $Ca(OH)_2$ titration methods were statistically similar. However, the average amount of lime rate determined with $Ca(OH)_2$ titration method was by 37.6% lower than the lime rate determined by SMP buffer method. This result is supported by Liu *et. al.* (2004) who found out that the 3-points prediction from the direct titration with 30 minute interval time between additions of 0.022M $Ca(OH)_2$ estimated approximately 80% of the soil acidity and LR determined by the widely accepted standard procedure for lime determination i.e., 3-day incubation of the soils with $Ca(OH)_2$. In the contrary, Liu *et. al.* (2004) also reported that titration of 1:1 soil:0.01 M $CaCl_2$ solution mixture with $Ca(OH)_2$ was more accurate than titrating soil:water mixture. According to Mclean *et. al.* (1978), titration of acidic soils with $Ca(OH)_2$ in l:5 (w:vol) soil:water suspensions (though the titration method differs from the method used in this study) yielded LRs that were similar to those obtained by the standard incubation with $CaCO_3$ to pH 6.5 over a 20 months period.

Table 8. Effect of application of lime rates determined with different lime testing methods on soil pH in 2014

Lime rate* ($CaCO_3$ t ha^{-1})	Site 1	Lime rate* ($CaCO_3$ t ha^{-1})	Site 2	Combined over sites
Control (0)	5.81b	0.0	6.20b	6.00b
SMP buffer (13.4)	6.49a	9.8	6.93a	6.71a
$Ca(OH)_2$ titration (8.8)	6.63a	8.0	6.74a	6.69a
PASP (0.3)	5.97b	-	-	5.97b
Mean	6.22	Mean	6.63	6.40
CV (%)	5.21	CV (%)	3.67	4.55
LSD (5%)	0.32	LSD (5%)	0.24	0.22

*Means with in a column followed by the same letter are not significantly different at 5% probability level.

Table 9. Effect of application of lime rates determined with different lime testing methods on soil pH in 2015

Lime rate* (CaCO$_3$ t ha^{-1})	Site 3	Lime rate* (CaCO$_3$ t ha^{-1})	Site 4	Combined over sites
Control (0)	5.75b	0.00	5.79	5.77b
Exch. acidity (0.32)	5.97ab	0.20	5.81	5.89ab
SMP buffer (3.30)	6.19a	1.20	5.98	6.08a
CaOH$_2$ titration (2.22)	6.10ab	1.26	5.87	5.98ab
Mean	6.00	Mean	5.86	5.93
CV (%)	6.57	CV (%)	4.02	5.43
LSD (5%)	0.39	LSD (5%)	ns	0.22

*Means with in a column followed by the same letter are not significantly different at 5% probability level. NS: Non-significant at 5% probability level.

CONCLUSION AND RECOMMENDATION

The result revealed that different lime testing methods generate different LR to raise the soil pH level to the desired level. It was found the SMP single buffer method and 3-point Ca(OH)$_2$ titration method to effectively increase the soil pH to the desired level. However, PASP and exchangeable acidity methods were found to underestimate the LR of acid soils in the study area. The LR estimated with Ca(OH)$_2$ titration method was by average 37.6% lower than the LR estimated with SMP buffer method. SMP buffer method was, therefore, found to overestimate the LR of acid soils in the study area. Thus, Ca(OH)$_2$ titration method was found to be the most appropriate and accurate lime estimation method among the methods evaluated in the study. Despite Ca(OH)$_2$ titration method was found to consume a little more time than SMP buffer method, it is recommended as the best LR determination method for routine use in soil testing laboratories as it can reduce about 38% of cost of lime expenses predicted by SMP buffer method.

As the buffer methods such as SMP buffer methods are rapid methods of lime testing for routine use in soil testing laboratories, developing conversion factor based on the recommended Ca(OH)$_2$ titration method is recommended to accelerate the soil testing process while maintaining the accuracy level. Moreover, a study on Ca(OH)$_2$ 1-point and 2-point titration evaluations on soil:0.01 M CaCl$_2$ mixture instead of soil:water mixture is worth further studying to shorten the time required for the soil testing. Although this study simultaneously verified the accuracy of the LRs predicted based on different lime testing methods on the field, calibration of the lime testing methods with the standard soil incubation procedures with CaCO$_3$ or Ca(OH)$_2$ is also recommended.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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