

*Full Length Research Paper*

# **Comparison of several lime requirement methods in Luvisol of Southern Ethiopia**

**Abebe Abay<sup>1\*</sup>, Tesfaye Hirpo<sup>2</sup>, Ayele Abebe<sup>2</sup> and Fikre Mekuria<sup>2</sup>**

<sup>1</sup>Ethiopian Environment and Forest Research Institute, P. O. Box 31037 Addis Ababa, Ethiopia.

<sup>2</sup>National Soil Testing Center, Addis Ababa, Ethiopia.

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**Ethiopian soil affected by strong acidity accounts for about 28% of the entire country and 43% of the total cultivated land. Soil acidity is expanding in scope and magnitude. To tackle the problem, lime addition is one of the solutions. The lack of soil specific lime recommendation method(s) to amend the increasing acidification problem has been one of the challenges to boost crop production. Therefore, a greenhouse experiment to select best-fit LR method(s) and calibrate on Luvisol was conducted. Different LR methods were evaluated to find out which of these methods most accurately predicted the LR in comparison with reference CaCO<sub>3</sub>-incubation. The initial LR dose for incubation experiment was calculated using Shoemaker, Mc lean and Pratt (SMP) method to achieve a target pH of 6.0, followed by progressive incremental addition of lime. Then, the soil was incubated with different doses of CaCO<sub>3</sub> for a period of five weeks to achieve different target pHs. The results of incubation were compared with the buffered and unbuffered LR methods. The CaCO<sub>3</sub> incubation pH measurement results showed an increasing trend with an increasing amount of lime added. The LR prediction ability of exchangeable acidity and single addition Ca (OH)<sub>2</sub> were the least of all the methods tested for Luvisol, when compared to the reference method. Adams Evan and modified Mehlich LR prediction are next to incubation in LR prediction for Luvisol. However, more researches that are detailed are needed to verify and synchronize the greenhouse results with field experiment in different agro ecologies to increase nutrient supply to the plant, water percolation and crop production.**

**Key words:** Acidity, luvisols, lime, lime requirement, Shoemaker, Mc lean and Pratt (SMP), modified Mehlich.

## **INTRODUCTION**

The agricultural sector for majority of Sub-Saharan Africa has not been able to guarantee food security at national and household levels (Bezu et al., 2014). The role of this sector is not different in Ethiopian status; even though it is the mainstay of the economy as well as the sector that determines the growth of all other national economy. The rapidly growing Ethiopian population needs

an increase in agricultural production, if not at double rate; it shall be at least at par to feed its population. However, the agriculture sector is characterized by uneven management practices and conflicts between competing uses: climate variability, land shortage, expansion to marginal lands and protected areas, soil acidity, alkalinity, deforestation and overall lack of proper

\*Corresponding author. E-mail: [abebeabayt@yahoo.com](mailto:abebeabayt@yahoo.com). Tel: 251911467157.

management of the land systems (Fox et al., 2018; Tamene et al., 2017; Teferi, 2018).

To mitigate these iniquities, understanding the soil physico-chemical properties have a lion's share role on managing the agricultural land, soil reactions and buffering action: which includes acidity and basicity of the soils. Wide areas of land in western, southern and the central highlands and even some pocket areas of central and northern parts of the country that receive medium to high rainfall are affected by soil acidity. Therefore, understanding how soil pH decreases and acidification rates vary across the soil types will assist in effectively managing and mitigating causes and aggravators of soil acidity. Acidification causes the loss of base cations, an increase in aluminum saturation and a decline in crop yields; severe acidification can cause nonreversible clay mineral dissolution and a reduction in cation exchange capacity, accompanied by structural deterioration (Goulding, 2016).

Ethiopian acid soils include slightly weathered Inceptisols, Entisols (highly weathered), Oxisols, Ultisols, intermediately weathered Alfisols, Vertisols, as well as Mollisols (Abebe, 1998).

Furthermore, Fageria and Baligar (2008a) had described at pH less than 5.0, toxic levels of  $Al^{3+}$ ,  $H^+$ , and sometimes  $Mn^{2+}$ , as well as deficiencies of many macro- and micronutrients, may limit plant growth (Haile et al., 2017; Taye, 2007). Ethiopian soil is affected by strong acidity level according to Kellogg (1993) classification which accounts for about 28% of the entire country and 43% of the total cultivated land. Moreover, Soil acidity is also expanding in scope and magnitude severely limiting crop yields (Yirga et al., 2019). The lack of soil specific lime recommendation to amend the increasing acidification problem has been one of the challenges to boost crop productivity in country. Thus, to mitigate soil acidity lime addition is one of the oldest practices in the world, which helps to improve soil, plants and grasses quality. From the benefits of a healthy soil, environment plants reap nutrients and become greener, stronger, use less water, as well as are more able to resist disease. In Ethiopia, LR are not yet studied based on soil types especially the Luvisols, which accounts 11.6% of the total land area of 1.3 million  $Km^2$  or 18% of the arable land of the country (Tolessa and Abdulahi, 2009).

Moreover, the amount of lime required to neutralize soil acidity depends on crop varieties, lime quality, farming system, amount of rainfall, acid buffering capacity of the soil, the neutralizing power of the liming material, soil depth as well as the consideration of the financial position of the farmers (Buni, 2014; Huluka, 2005a). Sims (1996) had also suggested that considerable research and practical experience shall be accompanied in different physiographic regions to determine the most accurate LR recommendations.

Conversely, over-liming can also reduce the bioavailability of Zn, Cu, Fe, Mn and B, which decreases with increasing pH (Fageria and Baligar, 2008b). This can

produce plant nutrient deficiencies, particularly that of Fe. Nonetheless, in different parts of the country, lime additions are made irrespective of soil the type and soil type specific methods (personal communication). The lack of soil type specific LR methods to amend the decreasing soil pH and declining crop yield has been one of the challenges in Ethiopia soils. Calcium carbonate incubation is one of the most reliable method to determine the LR of soils and to calibrations buffered and unbuffered methods (Bhumbla & McLean, 1965). However, incubation takes longer time than the other LR methods to reach the target pH. Thus, in order to study the lime requirement of Luvisol five methods, Vis-à-vis: Shoemaker, Mc lean and Pratt (SMP) (Shoemaker et al., 1961), Modified Mehlich (Hoskins, 2005), exchangeable acidity (Evans and Kamprath, 1970), as well as single addition of  $Ca(OH)_2$  (Kissel et al., 2007) and Modified Adams-Evans (A-E) buffer (Huluka, 2005a) were compared with the results of reference method.

## MATERIALS AND METHODS

### Description of the study area

*Sidama* is found in the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia. The highlands of *Sidama* get the highest amount of rainfall, ranging from 1600 to 1999 mm. It has a mean annual temperature of 15 to 19.9°C. *Molicho kebele* is found in *Hula* district of *Sidama*. The sample was collected from *Molicho*, found at N 6° 46' 65" and E 38° 55' 93" with altitudes 2768 m above sea level.

### Soil sampling and physico-chemical analysis

A representative, composited and geo-referenced Luvisol from *Molicho* site was collected up to a depth of 20 cm, using an Augur in a zig-zag design. The soil sample was air dried and pulverized to pass a 2.0 mm sieve for selected soil physico-chemical property analyses. The sample was further ground to pass 0.5 mm for total nitrogen and organic matter analysis. The experiment was conducted in complete randomized design in a greenhouse.

Particle size analysis was determined according to Bouyoucos (1951). Soil moisture contents; field capacity (FC, -0.3 bars) and permanent wilting point (15 bars) were also analyzed using pressure plate apparatus according to the procedure described by Hillel (1982). The pH- $H_2O$ , pH-KCl and electrical conductivity of the soil were measured in the ratio of 1:2.5 (soil: water) mixture according to (Van Reeuwijk, 2002). Soil organic carbon and total-N were determined using Walkley and Black (1934), as well as Nelson and Sommers (1980) respectively.

Exchangeable acidity and aluminum were determined from 1N potassium chloride leachate. The acidity brought into solution from various sources in the soil was then measured by titration with a standard solution of an alkali, the amount of alkali used being equivalent to the sum of the hydrogen and aluminum ions (exchangeable acidity). Then Aluminum was complexed with sodium fluoride, the exchangeable aluminum was measured by titrating the released alkali with standard acid (Thomas, 1982). The amounts of hydrogen ions were calculated from the difference between exchangeable acidity and aluminum ion. The cation exchange capacity was determined after treating the soil with



**Figure 1.** lime incorporation.

with appropriate solutions followed by distillation and titration according to Thomas (1982).

#### Lime incubation study

To select the best-fit LR method to amelioration Luvisol pH a comparison of the following methods were done in Greenhouse incubation experiment conducted at the National Soil Testing Centre, Addis Ababa, Ethiopia. SMP (Shoemaker et al., 1961) to determine the initial dose, Modified Mehlich a ratio of soil/water/buffer ratio of 1:1:2 as described by Hoskins (2005), single addition of  $\text{Ca}(\text{OH})_2$  (Kissel et al., 2007), exchangeable Al method developed by Evans and Kamprath (1970) and modified by Adams Evan (Huluk, 2005b) were used in the experiment. All data obtained from the experiment were compared with the standard reference incubation method. The soils were mixed thoroughly and incorporated with increasing doses of reagent grade  $\text{CaCO}_3$ , equivalent to 0.00, 7.06, 8.82, 10.58, 12.35, 14.11, 15.88, and 17.64 ton/ha in three kg pots in replication (Figures 1 and 2). The initial calibration values estimated to reach a target of pH 6.0 was taken from (Lierop 1990) which is developed based on Shoemaker et al. (1961). The experiment was commenced the same day the lime was incorporated and it was watered to 90% field capacity at 2-3 days interval. The incubation was continued for a period of 5 weeks in a greenhouse and each pot was sampled independently at 1st, 2nd, 3rd, 4th, and 5th week stage for the determination of pH until the pH showed relative constant readings.

#### Statistical analysis

To compare the precision of the LR methods regression equations fitted to relationships between incubation, buffered and unbuffered were used. The data were subjected to the analysis of variance (ANOVA) to assess the significance differences in soil pH between treatments and different buffering methods, using the general linear model (GLM) procedure of the statistical analysis system (Institute, 1996). A post hoc separation of means was done using LSD test

after main effects were found at significant  $p < 0.05$ .

## RESULTS AND DISCUSSION

### Physico-chemical properties

The pH-  $\text{H}_2\text{O}$  and the pH-KCl of the soil were 5.10 and 4.16 respectively. The primary use of the pH salt (soil: 1N KCl solution) was to test the presence of exchangeable aluminum. This salt solution displaces hydronium and aluminum ions completely. The Aluminum displaced by  $\text{K}^+$  consumes  $\text{OH}^-$  ions and increases  $[\text{H}^+]$ . As a result, the soil pH values in pH salt become lower. The delta pH (pH-KCl minus pH-  $\text{H}_2\text{O}$ ), which is used as a diagnostic tool for the nature of the net charge on the colloidal system, showed that the soil had a net negative charge, which indicated cation-exchange capacity, is the concern rather than an anion-exchange capacity on soil colloid.

Thus, the exchangeable Al content of this soil was relatively low (0.21 meq/100 g), which does not impose a direct threat for crop production. In general, Aluminum level greater than 2.5 meq/100 g are considered to be very toxic, 1.0 - 2.5 meq/100 g high 0.5 to 1.0 medium and less than 0.5 meq/100g are considered low toxic according to (Sparks D.L., n.d.) classification. Thus, this soil is not in aluminum toxic range. The CEC value of the soil (21.83 Cmol/Kg) is rated in medium range according to Havlin et al. (2010) rating. The pH- $\text{H}_2\text{O}$  of the soil lies in strong acidic range according to Kellogg (1993) classification, this may have contributed to the medium CEC range resulted from leaching of the cations. According to Havlin et al. (2010), rating the electrical



**Figure 2.** Incubation experiment in greenhouse.

conductivity (EC) of the soil was categorized in very low range. In addition to this, TN content of the soil according to Landon (1996) is categorized under the “medium” category.

According to McKenzie et al. (2004), rating soils having bulk density greater than  $1.6 \text{ Mg/m}^3$  tend to influence and restrict root growth. However, the soil in this study has lesser value; implying that there is no excessive compaction and restriction to root development. Therefore, based on the Physico-chemical analysis data, the nutrient status of Luvisols was in suitable range to stimulate the LR study (Table 1).

### Calcium carbonate incubation

The incubation experiment showed an increase in pH values in linear relationship with the applied lime ( $\text{CaCO}_3$ ) rates commencing the first week (Figure 3). The highest dose showed the highest increment in  $\text{pH-H}_2\text{O}$ . However, there was no significant change in third to fifth weeks at a dose of  $10.584 \text{ t/ha}$  at  $\text{pH-H}_2\text{O}$  6.20 to 6.30 (Table 2). The change in pH was completed in five weeks. The reason for the fast rise in pH could be deduced: the clay composition and medium organic matter content of the soil had less-pressed on the buffering capacity of the soil. Keller and Matlack (1990) showed that in kaolin-family clay, the pH of the soil tends to go as low as pH 4 to 5.

Moreover, soils having high organic matter content can have high buffering capacity (Fageria and Baligar, 2008a; Paul 2014; Rengel, 2011).

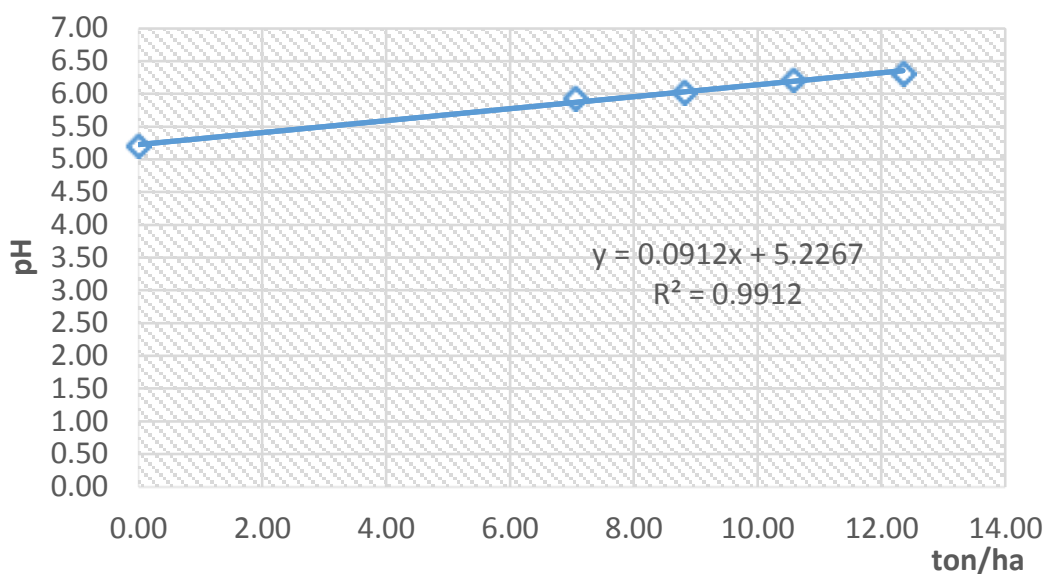
The second reason for the fast change in pH value could be reasoned out by the fineness of lime material used and the initial  $\text{pH-H}_2\text{O}$  of the soil. The regression equations obtained from the lime application rates and pH increment after five weeks of incubation were highly correlated ( $r^2 = 0.9912$ ), (Figure 3). This high correlation suggests that a better LR range can be estimated from the calibrated and derived equation. Thus, using the adjusted regression equation LR can be calculated for different pH values at high correlations ( $r^2 = 0.9912$ ) for Luvisol.

### Single addition calcium hydroxide

The pH measured in soil-calcium hydroxide solution showed values 5.84 to 7.04 upon portion-by-portion addition of 3 ml calcium hydroxide solution until 12 ml was reached. Then a linear regression titration curve was produced from the added aliquate versus the resulting pH of the soil. The pH value without buffer addition was omitted because this value was below the y intercept, but all remaining data up to pH 7.04 were included. To calculate LR for Luvisols using single addition of calcium

**Table 1.** Physico-chemical properties of Luvisol.

Parameter	Unit	Value
pH-H <sub>2</sub> O		5.10
pH-KCl		4.16
EC	(dS/m <sup>2</sup> )	0.13
Clay	(%)	34
Silt	(%)	36
Sand	(%)	30
Class	-	Clay loam
Bulk density	Mg/m <sup>3</sup>	1.41
CEC	Cmol(+)/kg	21.83
OC	(%)	4.16
TN	(%)	0.38
C/N	-	12
Exchangeable acidity	(Cmol(+)/kg)	0.33
Exchangeable Al <sup>3+</sup>	(Cmol(+)/kg)	0.21
Exchangeable H <sup>+</sup>	(Cmol(+)/kg)	0.12

**Figure 3.** The rise in pH as amount of lime added in Luvisol incubation study.

hydroxide, the weight of soil titrated (0.02 kg) and bulk density were considered. The slope was calculated using the equations derived by Kissel et al. (2007):

$$\text{Slope} = \frac{(pH_2 - pH_1)}{(V \times M \times 100 \text{ mg CaCO}_3/\text{mmol CaCO}_3)/\text{weight of soil}}$$

In this equation,  $pH_1$  is the pH value before addition of  $\text{Ca}(\text{OH})_2$ , and  $pH_2$  is the pH value after addition of  $\text{Ca}(\text{OH})_2$ ,  $V$  is volume added and  $M$  is the molarity of the buffer. Despite the differences between the procedures followed by *Single Addition of Calcium hydroxide* and the well-

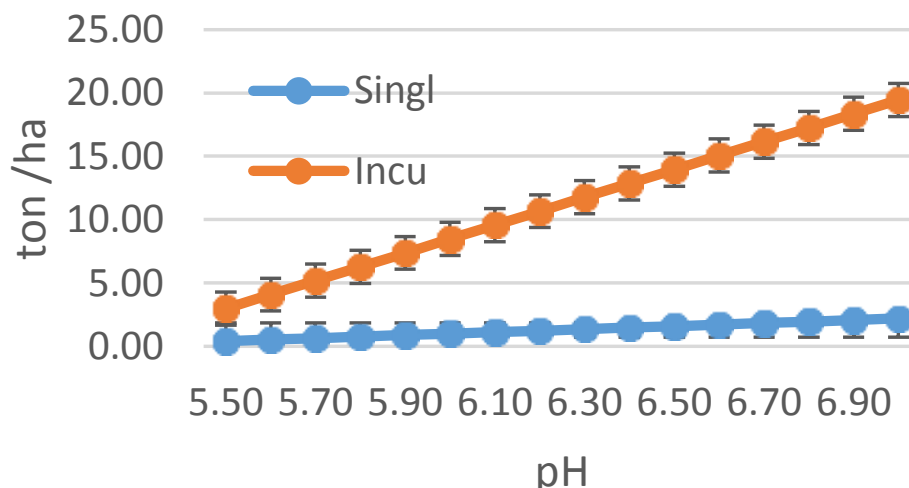
established incubation methods, the lime quantities prescribed by both calibrations to reach different target pH values for Luvisol were compared. This comparison reveals that if both doses are going to be used to attain same target pH value using identical quantities of limestone, the single addition calibration prescribes lower lime amount in relation to the reference incubation method (Figure 4). This implied that, the lime applied using the *Single Addition of Calcium* method does not fully ameliorate the soil to the desired pH. To improve the LR predictions of the single addition  $\text{Ca}(\text{OH})_2$  method in Luvisols, a regression equation was derived to obtain a

**Table 2.** Interaction effect of lime rates, pH and weeks in Luvisols.

Week	(T0)	(T1)	(T2)	(T3)	(T4)	(T5)	(T6)	(T7)
	0.00	7.06	8.82	10.58	12.35	14.11	15.88	17.64
1	5.103O	6.283 <sup>kji</sup>	6.593 <sup>egf</sup>	6.763 <sup>edc</sup>	6.770 <sup>edc</sup>	6.950 <sup>bac</sup>	7.1033 <sup>a</sup>	7.033 <sup>ba</sup>
2	5.110O	6.133 <sup>kml</sup>	6.300 <sup>kji</sup>	6.553 <sup>hgf</sup>	6.787 <sup>edc</sup>	6.537 <sup>hgf</sup>	7.030 <sup>ba</sup>	7.127 <sup>a</sup>
3	5.106O	6.030 <sup>ml</sup>	6.027 <sup>ml</sup>	6.300 <sup>kji</sup>	6.460 <sup>hgi</sup>	6.793 <sup>edc</sup>	7.020 <sup>ba</sup>	7.0933 <sup>a</sup>
4	5.103O	5.813 <sup>n</sup>	6.173 <sup>kjl</sup>	6.217 <sup>kjl</sup>	6.373 <sup>hji</sup>	6.550 <sup>hgf</sup>	6.703 <sup>edf</sup>	6.853 <sup>bdc</sup>
5	5.103o	5.930 <sup>nm</sup>	6.117 <sup>kml</sup>	6.210 <sup>kjl</sup>	6.307 <sup>kji</sup>	6.630 <sup>egf</sup>	6.740 <sup>edf</sup>	6.870 <sup>bdc</sup>
LSD (0.05)		0.1207						
CV (%)		0.0856						

Treatments in a column followed by the same superscript letters are not significantly different

Note: T\* (0 to 7) stands for treatment in tone/ha.



**Figure 4.** Comparison of single addition of Ca (OH)<sub>2</sub> incubation.  
Source: Error bars represent  $\pm 1$  SE.

better fit equation to meet the lime prescribed by incubation experiment (Figure 5). Thus, the following equation was derived to convert results obtained by *Single Addition of Calcium* bring as incubation method prescribed.

$$\text{LR (equivalent to incubation)} = (9.2 \times \text{LR from } \textit{Single Addition of Calcium}) - 0.80 \quad (1)$$

### Modified Mehlich buffer

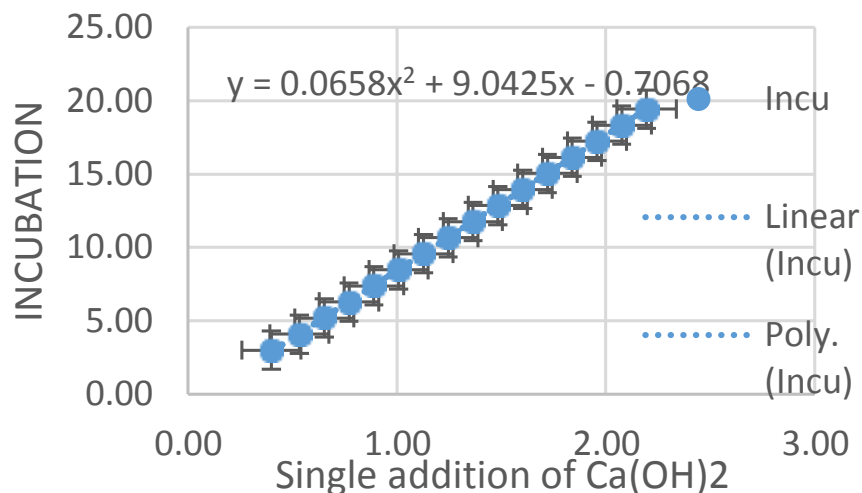
To predict the lime requirement of Luvisol using modified Mehlich buffer method, the equations proposed (Hoskins, 2005) Equations 2 and 3 were used. The initial pH value of the buffer was 8.0. The sensitivity of this buffer, as indicated was measured by the size of the decrease in soil-buffer pH for a given LR. The LR rates were calculated with the regression equation derived

from the data obtained by Modified Mehlich method for different target pH Values. The doses were compared with the reference lime recommendations.

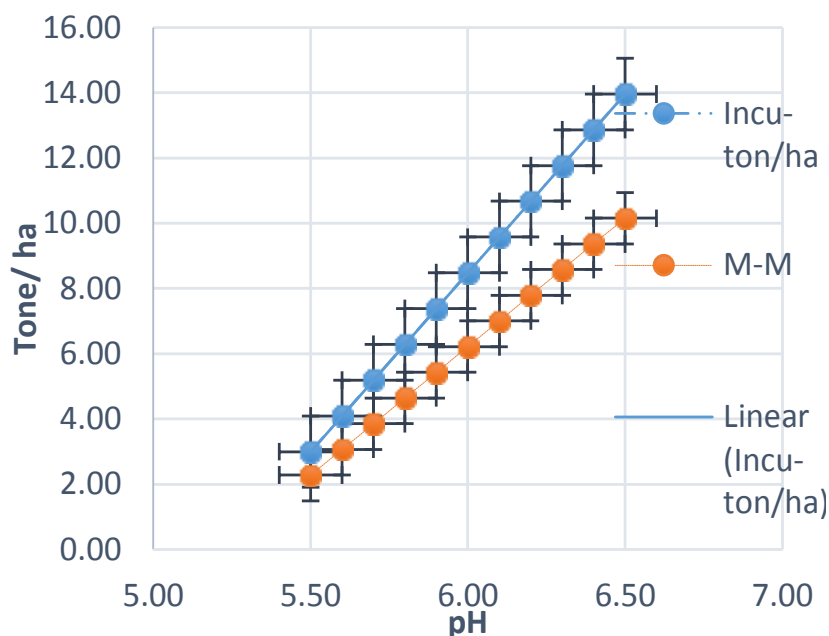
$$\text{Mg lime ha}^{-1} = [(\text{Buffer pH} - \text{soil: buffer pH}) / 0.25] \times [(\text{target pH} - \text{soil pH}) / (\text{buffer pH} - \text{soil pH})] \times 2.2 \quad (2)$$

$$\text{LR (ton/ Ac)} = \text{Buffer pH acidity} \times [(\text{target pH} - \text{soil pH}) / (6.6 - \text{soil pH})] \quad (3)$$

Simultaneously, the recommendations obtained from single addition of Ca(OH)<sub>2</sub> were compared with LR rates calculated from modified Mehlich. Thus, the LR obtained by single addition of Ca(OH)<sub>2</sub> estimates lower values than that of calculated values by corrected modified Mehlich soil-buffer. Nevertheless, lower than the LR made by reference incubation. This implies that the lime to be added to reach the target pH was not sufficient to attain



**Figure 5.** Conversion of results single and addition to incubation. Source: Error bars represent ±1 SE.



**Figure 6.** LR Comparison study for incubation Modified Mehlich Buffer. Source: Error bars represent ±1 SE.

the intended pH in actual cases (Figure 6). To improve the LR prediction and to cover the full range of LR values using this method or to recommend equivalent dose as the reference in incubation study, the equation has to be modified as in Figure 7.

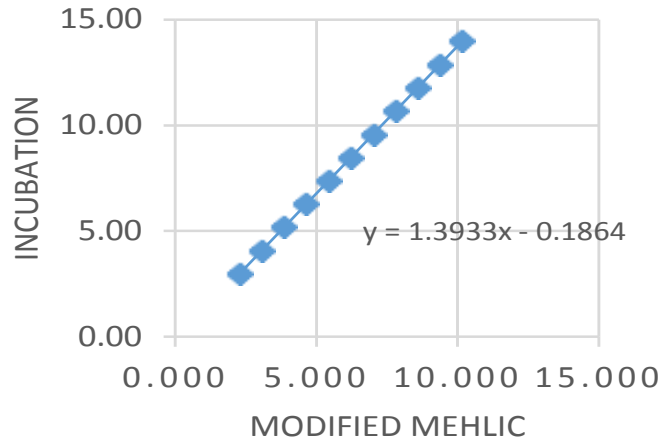
$$Y = 1.3933X - 0.1864$$

Where, Y= incubation (t/ha) and X= results obtained from

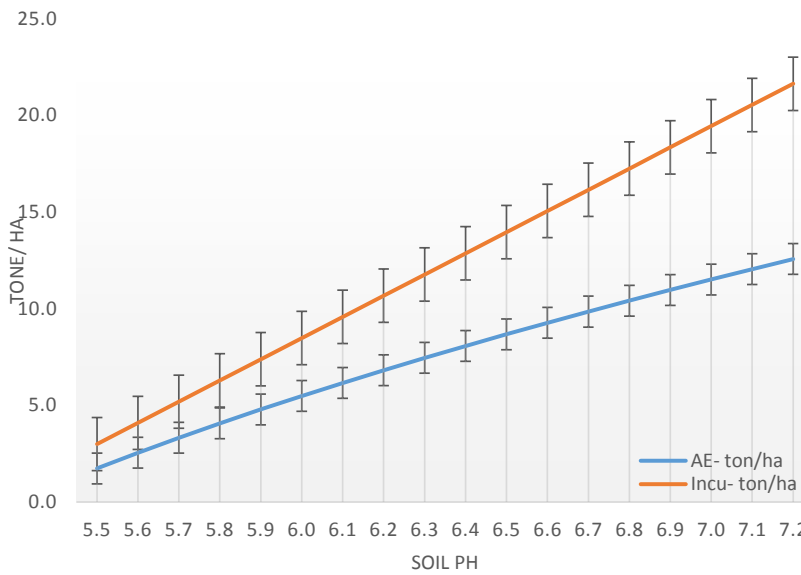
Modified Mehlich (t/ha).

**Exchangeable acidity**

The LR rates prescribed by this method, according to the original calibration, were not intended to achieve any particular soil pH but rather to neutralize that portion of the soil acidity presumed harmful to plant growth up to



**Figure 7.** LR Comparison study for incubation and Modified Mehlich Buffer.  
Source: Error bars represent ±1 SE.



**Figure 8.** Comparison of modified Adams- Evans and incubation LR.  
Source: Error bars represent ±1 SE.

5.5 pH-H<sub>2</sub>O (Sparks D.L., n.d.). The amount of lime required to reach the desired pH, calculated by using acidity equation is much lower than those derived equations, proposed by buffered test methods in this study. In addition to this, ameliorating Luvisol using (Evans and Kamprath, 1970) Equation 4, underestimates the amount of lime needed to reach the target pH when compared to the reference method. Thus, the study showed that a corrected lime equation should be derived to achieve the desired pH as incubation did.

$$LR, CaCO_3 (kg ha^{-1}) = \frac{Cmol EA / kg soil \times 0.15 m \times 10^4 m^2 \times B.D (mg / m^3) \times 1000 \times 1.5}{2000} \quad (4)$$

Where; EA = Exchangeable acidity; B.D = Bulk density, and EA = Exchangeable acidity

### Modified Adams-Evans (A-E) buffer

A regression equation showing the relationship among LR of *Adams-Evans (A-E) buffer* and the change in pH was developed. The result of the study showed that as the lime doses increase the change in pH changed linearly ( $r^2=0.9999$ ). However, the LR was also less than that determined by incubation (Figure 8). As the target pH



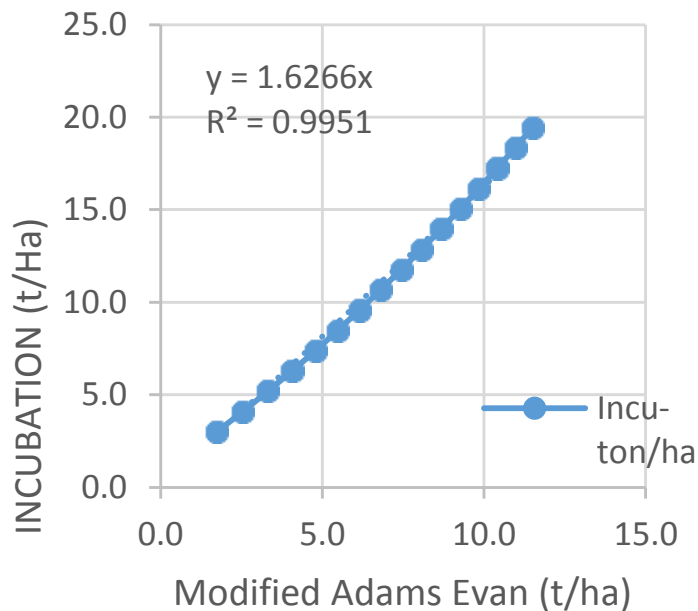


Figure 9. Comparison of Modified Adams Evan and incubation.

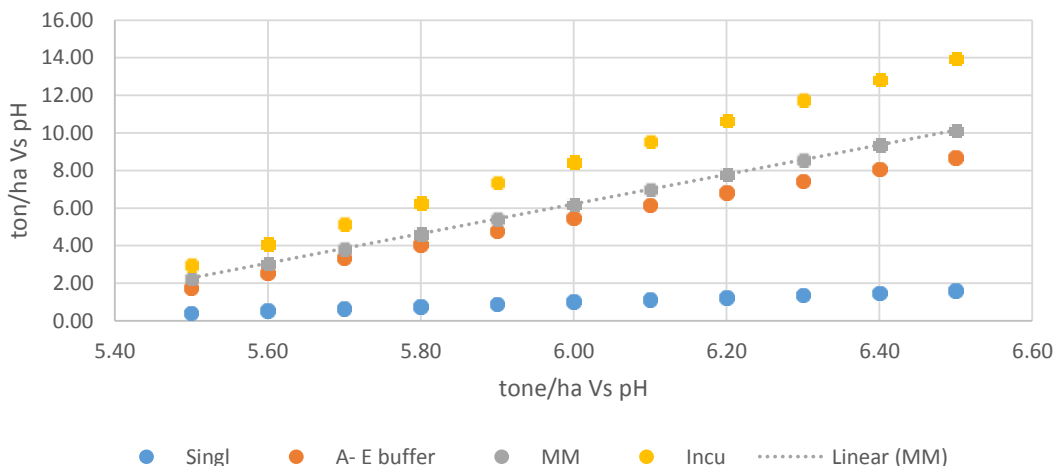


Figure 10. Comparison of different lime requirement in Luvisol as compared to Incubation.

increased, the practical prediction of Adams-Evans Buffer was declining when compared to low pH values. This study revealed that Adams-Evans (A-E) buffer calibration underestimates the LR when compared to the reference method. Thus, to convert results obtained by AE to actual incubation the following equation can be used at  $r^2=0.9951$  (Huluka, 2005a) (Figures 9 and 10). The treatments of lime equations as can be seen from

$$Y = 1.626X - 0.1864$$

Where, Y = incubation (t/ha); X= results obtained from AE

(t/ha).

### Conclusions

The choice of better lime requirement method for adjusting the soil pH to reach the target pH is indispensable. The comparison and evaluation of Shoemaker, Mc lean and Pratt (SMP), Adams-Evan, Modified Mehlich, Exchangeable acidity as well as single addition of  $Ca(OH)_2$  methods with the well-established and reference method  $CaCO_3$ -incubation method revealed

that conversion factors are required. The study showed that there were significant correlations between all the methods in the study. There upon, the single  $\text{Ca}(\text{OH})_2$  addition predicted least precise to achieve the target pHs, while modified Mehlich and Adams Evan buffers method predicted better LR as compared to single  $\text{Ca}(\text{OH})_2$  addition to achieve different target pHs. Thus, the LR required by Exchangeable acidity, incubation, single addition of Calcium hydroxide  $\text{Ca}(\text{OH})_2$ , Modified Mehlich Buffer and Modified Adams-Evans (A-E) buffer are 0.093, 3.0, 0.41, 0.92 and 1.74 tone/ha respectively to reach the desired pH 5.5. The main advantages in the procedures used to derive the modified LR from the standard calibration methods obtained in this study are as follows: probably, if one of these calibrated and standard lime amelioration methods is used for Luvisols, it may be advantageous to merely modify the same buffer with the procedure-derived equations in this study.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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