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Comparison of Lime Requirement Determination Methods to Amend Acidic Nitisols in Central Highlands of Ethiopia

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የአፈርን ኮምጣጣነት ለመቀነስ ኖራን መጠቀም አንዱ ጠቃሚ ዘዴ መሆኑ ይታወቃል፡፡ ይሁን እንጂ የኖራ መጠን የምንመጥንበት የአሰራር ሂደት ተለይቶ ባለመታወቁ ቅድሚያ መሰጠት የሚገባው የምርምር ርዕስ ነው፡፡ ስለዚህ ይህ የምርምር ሙከራ በኮምጣጣ ቀይ አፈር (ኒቶሶል)ላይ ታቅዶ ሙከራው በ2009 ዓ.ም በሆለታ ግብርና ምርምር የአፈር ትንተና ላቦራቶሪ የተሰራ ነው፡፡ የተለያዩ የኖራ መመጠኛ ዘዴዎችን ማለትም የተሻሻለ የአዳምስ ኢቫንስና የመሊች በፈር እንዲሁም ታይትሬሽን አሰራሮችን በመጠቀም የኖራ መጠን ተወስኗል፡፡ እነዚህ አሰራሮችም በእንኩቤሽን ዘዴ እንድፈተሹ ተደርገዋል፡፡ ውጤቱ እንደሚያሳየው የመሊች በፈር እና ታይትሬሽን አሰራሮችን በመጠቀም የኖራ መጠን መወሰን በኮምጣጣ ቀይ አፈር ላይ ሰብል ለሚያመርቱት አርሶ አደሮች የሚያስፈልገውን የኖራ መጠን ለይቶ ለማወቅ የተሻለ መሆኑን ያመላክታል፡፡

Abstract

Liming acid soils is one of the available intervention options to amend soil acidity and increase crop production and productivity. Nevertheless, selection of lime requirement determination method suitable to the soil conditions in a particular area is a pressing issue. Therefore, this research was carried out to evaluate lime requirement determination methods to amend soil acidity, in Holetta Agricultural Research Center laboratory in 2017. A total 24 soil samples were collected from acidic Nitisols in the central highlands. The buffers of modified Mehlich (MMB) and modified Adams-Evans buffers (MAEB) were separately prepared. Initial soil pH; soil, water and buffer pH measurements were taken. Soil pH buffer capacity was calculated for each buffer solution from the change from initial pH water and buffer pH. The titrations were performed and lime rate determined. Finally, lime rates determined were validated by soil incubation. The MAEB, MMB and titration with 0.022 M $Ca(OH)_2$ *methods predicted the lime requirement at the rate of 24.7, 4.0 and 3.12 t* ha^{-1} *respectively. The MMB and titration methods predicted the LR almost in the range affordable to the farmers who produce crops on Nitisols. Contrary to this, the MAEB method overestimates LR above the requirements of the soil. Therefore, areas covered with Nitisols can use the Modified Mehlich Buffer or titration to determine the lime rates required to amend their soils. However, field calibrations are required using crops soil pH requirements before these tested methods are taken the best methods to amend the acidic Nitisols to pH 6.0.*

Introduction

Soil acidity is a complex of several factors involving plant nutrient deficiencies and toxicities, low activities of beneficial microorganisms, and reduced plant root growth which limits absorption of nutrients and water (Fageria and Baligar, 2003). This is the most serious challenges to agricultural production and productivity worldwide in general (Athanase *et al*., 2013). At a global level, areas affected by soil acidity (pH < 5.5 in the surface layer) constitute 3,950 million ha of land, which is about 30% of the world's total ice-free land (Sumner and Noble, 2003).

Even though, variability exists in the extent, all continents on the planet have soil acidity problems. From 3.01 billion ha in Africa, 659 million ha of land (22%) is acidic soil (Malcolm and Andrew, 2003). Most of these acidic soils are found in tropical and subtropical African countries such as Tanzania, Kenya, Uganda, Ethiopia, etc. In Ethiopia 43% of the total arable land is acidic (Behailu, 2015), which host 88% of the human and 86% of the livestock populations (Amsalu *et al.*, 2007; Behailu, 2015). These over populated areas are concentrated in the highlands and accounts for about 95% of the total cultivated lands (Sonneveld and Keyzer, 2003). Around 27.7% of the soils are dominated by moderate to weak acidic reaction (pH 4.5-5.5) while 13.2% are strongly acidic (pH <4.5) in KCl (Schlede, 1989 and Mesfin, 2007).

According to Behailu (2015) and Mesfin (2007) soil acidity is expanding in scope and magnitude across different regions of Ethiopia, becoming a serious threat to crop production in the western, southern, northwestern and central highlands. This is attributed to higher precipitation, which exceeds evapotranspiration that subsequently leaches appreciable amounts of exchangeable bases from the soil surface. As a result, most of the soils have a pH range of 4.5 - 5.5, low OM content (<20 g/ kg) and low available plant nutrients (Temesgen *et al*., 2011). Soil acidity has negative impact on nutrient availability and causes Al and Mn toxicity (Osundwa *et al*., 2013). Furthermore, soil acidity can cause rapid deteriorations in soil physico-chemical properties such as soil organic carbon (OC), cation exchange capacity (CEC), soil structure, porosity, and texture. Acidification has effect on complexation of metals with organic matter, dispersion of colloids and eventual bioavailability and trace elements (Bolan *et al*., 2003). Decrease in pH leads to increase in net charge (low in CEC) which leads to lose of soil fertility and ultimately reduces land productivity.

Liming acid soils is one of best available intervention options to mitigate the negative effects of soil acidity and increase crop production and productivity (Slattery and Coventry, 1993). Several authors tested lime on different crops Getachew *et al*. (2017) on barley at Bedi; Geremew *et al*. (2015) on potato at Bedi, Holetta and Cheha; Mekonnen *et al*. (2014) on bread wheat at Gozamin, Tesfaye *et al*., (2016) on common bean at Areka and recorded contribution of lime to increased yield of tested crops. Getachew *et al*. (2017) reported grain yield advantage of 274.0% by lime application as compared to unlimed plots on barley field on Nitisols of Bedi, central highlands of Ethiopia. Similarly, Farhoodi and Coventry (2008), reported 70-75% yield increments of barley, wheat and faba beans; and 30% of durum wheat a year after lime application.

Other researchers also reported that lime application improved grain yield of many crops (Liu *et al*., 2004; 2005; Achalu *et al*., 2012; Woubshet *et al*., 2017).

Lime rate determination requires total acidity estimation of the soil, including the capacity (fraction of reserve, exchangeable, and soluble acidity) and intensity (soil solution acidity) factor. Buffer solutions resist abrupt change in pH and have been used to determine the amount of liming materials needed to raise soil pH to a desired target value and are expected to measure both the capacity and the intensity factors of soil acidity (Gobena, 2005). According to this author, the ability of buffer solutions to measure the capacity factor of soil is the main reason for their extensive use.

Methods based on pH or exchangeable Al or acidity (Al + H) are incapable of accurately estimating the acidity hazard across textural classes, especially if there are marked differences across soils in terms of their physical and chemical properties. Soil pH measurement only gives the concentration of dissociated hydrogen (H^+) ions in solution, which is a very small fraction of the total acidity present. From this point of view, it is clear that determination of LR based on exchangeable acidity only leads us to unrealistic rate of lime to reclaim soil acidity (Farina *et al.,* 1991). Therefore, LR should be determined based on soil's pH and its buffering capacity, which is determined by soil texture, type of clay minerals, and the amount of OM (Aitken *et al*., 1990).

The modified Adams-Evans buffer (MAEB) solution is easy to prepare because KH_2PO_4 easily dissolves in water. It is more suitable to work with in the laboratory and is also environment friendly (Gobena, 2005). Another buffer solution, Mehlich buffer was developed to estimate the exchangeable acidity of the soil and to correlate it with the LR recommendation (Mehlich, 1976; Wolf *et al.,* 2005). Mehlich buffer was modified by Hoskins (2005) and named modified Mehlich buffer to overcome the drawbacks of the Shoemaker–McLean–Pratt (SMP) buffer procedure.

Titration is another method to determine lime rate, direct titrations that give an estimate of exchangeable acidity (McLean *et al*., 1977) and soil incubations are often used to calibrate different methods. Dunn (1943) studied direct titration to predict the LR of acid soils and focused on the time to reach equilibrium for the reaction between the added base and the acidic soils. He found that four days were required to reach equilibrium when 0.022 *M* $Ca(OH)_2$ solution was added to an acid soil.

Incubation method is considered reliable to validate the buffer and titrations but it is time consuming (Bache, 1988) and long-term incubations are likely to lead to mineral nitrogen accumulations and the associated pH changes (Barrow and Cox, 1990). They found that because of the increased rate of reaction at high temperatures, it is possible to produce in a few days at 60^{o}C to effects similar to several months' incubation at 25^{o}C, the use of room temperature with incremental mixtures of $CaCO_3$ and soil tends to overestimate the actual LR (Baker and Chae, 1977). Some literatures indicated that a 24 hrs incubation period is sufficient to reach equilibrium if highly reactive bases are used. Others indicated that about a week may be required, some still recommend a suitable period of incubation of a month or more needed. Pantelis *et al.* (2013) finally indicted that 72 hrs incubation is enough with $Ca(OH)_2$ or $CaCO_3$.

Several laboratories use different methods even though no better method has been preferred for the rate of lime that fit for amendment of the acid soils. Therefore, selection of method of lime requirement that would be accurate, rapid, environmental friendly and better suited for routine soil analyses have been a pressing issue for acid soils management. In line with the above facts, this research activity was carried out to evaluate different lime requirement determination methods for amendment of acidic Nitisols in the central highlands of Ethiopia.

Materials and Methods

Soils sampling and sample preparation

The experiment was conducted in Holetta Agricultural Research Center laboratory in 2017. Twenty-four soil samples were collected from acidic Nitisols in West Shewa, in central highlands of Ethiopia. The collected soil samples were packed in a plastic bag labeled and taken to soil laboratory for preparations and analysis. The soil samples were air-dried ground and sieved before analysis.

Analysis of Soil Samples

The pH of the soil was measured potentiometrically using a pH meter in the supernatant suspension of 1:1 soils to liquid ratio of water (Van Reeuwijk, 1992). Particle size distribution of soils was analyzed by hydrometer method (Bouyoucos, 1962). Soil bulk density was analyzed by the method set by George *et al.* (2013). The Walkley and Black (1934) wet oxidation method was used to determine soil OC. Total nitrogen (TN) content of the soil was determined by digestion procedure of the Kjeldahl method (Bremner and Mulvaney, 1982).

Available phosphorus (AP) was determined using the standard Bray-II (Bray and Kurtz, 1945) extraction methods. Absorbance of AP extracted by Bray-II was measured using spectrophotometer after color development. Exchangeable basic cations (Ca, Mg, K, and Na) were determined after extracting the soil samples by 1N neutral ammonium acetate (1N NH_4OAc) solution adjusted to pH 7.0. Exchangeable Ca, Mg, K, and Na in the extract were measured by atomic absorption spectrophotometer (AAS) (Okalebo *et al.*, 2002). The CEC was determined from the ammonium acetate saturated samples through distillation and measurement of ammonium using the modified Kjeldhal procedure as described by Okalebo *et al.* (2002). Exchangeable acidity (Al^{+3} and H^{+1}) and exchangeable Al were determined by saturating the soil samples with 1N KCl solution and the filtrate was titrated with 0.02N NaOH and 0.02N HCl, respectively, as described by Rowell (1994).

Determination of lime requirement by buffer methods

Soil pH measurements were made in 1:1 soil to water ratio for buffer preparation in two replicates. The buffers of modified Mehlich (MMB) (Hoskins, 2005) and modified

Adams-Evans (MAEB) (Gobena, 2005) were separately prepared following their own standard procedures. Ten ml of each buffer was added in prepared pH water (1:1:1 soil/water/buffer) ratio. The sample was stirred with a glass rod for 30 seconds and allowed to settle for 30 minutes. A soil-water-buffer pH measurement was taken while stirring and recorded as pH buffer (pHB). Soil pH buffer capacity was calculated for each buffer solution from the change in buffer pH according to the method set by Gobena (2005) and Hoskins (2005), the buffer capacity of the buffer solution (thus giving the amount of acidity consumed from the soil) and change in soil pH water. Soil samples with relatively high and low pH $_{(H2O)}$ values were included in this study to examine the applicability range of each method.

Determination of lime requirement by titration

Total acidity titration by $Ca(OH)_2$ was measured for LR determination and to compare with the amounts indicated by the various buffer methods. Soil pH was measured in a soil/water (1:1) suspension (pH H_2O) and in a soil/0.01 M $CaCl_2$ (1:1) suspension (pH $CaCl_2$), soil pH readings were taken and the results were recorded as pH data group I and II, respectively. The titrations were performed with 0.022 M $Ca(OH)_2$ to a final pH of 6.0 with 3 mL of base per addition based on Liu *et al*. (2004). The LR (t ha^{-1}) was calculated using the method developed by Pantelis *et al*., (2013) as;

$$pHt = pHa + b + v, \quad from\ this \quad v = \frac{pHt-pHa}{b} \tag{1}$$

$$LR(\mathrm{MgCaC}O_3\ ha^{-1}) = v * M * \frac{100mgCaCO_3mmol}{CaCO_3} * \frac{10^{-9}MgCaCO_3}{mgCaCO_3} \tag{2}$$

$$(MgCaCO_3) = v * (2.2 * 10^{-9}) \tag{3}$$

$$LR(\mathrm{MgCaC}O_3\ ha^{-1}) = \left(\frac{\mathrm{MgCaC}O_3}{\frac{\mathrm{ws}}{\mathrm{MS}}}\right) \tag{4}$$

$$LR(\mathrm{MgCaC}O_3\ ha^{-1}) = v * 0.33 \tag{5}$$

Combining equations (1) and (5)

$$LR(\mathrm{MgCaC}O_3\ ha^{-1}) = (pHt - pHa) * 0.33 \tag{6}$$

where ; b- slope of the titration curve, v- Volume (ml) of 0.022 M $Ca(OH)_2$ added, M- Molar of $Ca(OH)_2$, pHt- target pH, pHa- initial reading of the soil pH, ws- working sample weight in kg, Mg- mega gram (unit) and MS- soil mass in a hectare in kg.

Validation of the methods using incubation

Incubation was carried out for soil and lime rates determined using above methods titration, MMB, and MAEB to validate the LR determination methods indicated, whether the predicted LR could bring the soil to pH 6. The soils collected from different cultivated lands from depth of 0 to 15 cm were composited to one sample. A soil (100 g) and $Ca(OH)_2$; equivalent to $CaCO_3$ (adjusted meq $100g^{-1}$ soil) was mixed at the rates 0, 50, 100, 150, and 200% of the estimated LR. The soil and lime were incubated for 3 to 30 days in three replications under room temperature with moisture content at field capacity. After 3, 6, 12, 18, and 30 days, the soil samples were air dried, ground and sieved to pass through 2 mm size mesh, and soil pH $_{(}H_2O_{)}$ determined.

Statistical analysis

The soil analytical data were subjected to statistical analysis. The pH recorded before and after titration and buffer methods and LR determined was subjected to regression analysis by excels spreadsheet, to determine the lime rates based on the initial soil pH $_{(H2O)}$ of the soil.

Results and Discussion

Soil Physical and Chemical Properties

Physico-chemical properties of the study soils are indicated in Table 1. The clay content was in the range of 37-65 with a mean value of 49±1.2% with soil textural class of clay. Soil bulk density ranged from 1.11-1.28 g cm^{-3} with mean of 1.17±0.01 g cm^{-3}. The soil was medium in TN and low OC content (Berhanu Debele, 1980).

The pH of the soil samples used in this study was very strongly acidic, according to the rating given by Jones (2003). The range for exchangeable acidity (Ac), exchangeable Aluminum (exAl) and CEC were 0.1-3.4, 0-1.94, and 16.5-33; with mean value of 1.4±0.2, 0.8±0.09, and 20.5±0.7 respectively. The CEC of the soil was medium as rated by Landon (1991), Hazelton, and Murphy (2007). The available phosphorus (AP) of the soil was very low according to rating by Jones (2003). Exchangeable Ca, Mg, K, and Na contents of the soil were medium, high, medium, and low respectively according to rating by FAO (2006). The soil of the study area was the most buffered because of the soils CEC (20.5) and its clay textural class (Table 1).

Table 1. Physico-chemical properties of the study soils (n=24)

Level	Soil Properties														
	pH (1:1) H_2O	BD (g/ cm^3)	AP (ppm)	Clay	Silt	Sand	TN	OC	CEC	Ca	Mg	K	Na	Ac	exAl
				-------------------(%)---------------					-------------------------($Cmol_{(+)}kg^{-1}$)-----------------------						
Min.	4.56	1.11	2.93	37	7	12	0.10	0.6	16.5	5.5	1.8	0.004	0.005	0.1	0.00
Max.	5.54	1.28	11.41	65	40	29	0.35	2.4	33.0	12.0	8.3	0.62	0.111	3.4	1.94
Mean	4.85	1.17	7.02	49	29	22	0.25	1.9	20.5	7.5	3.4	0.34	0.03	1.4	0.84
median	4.79	1.16	7.51	48	29	22	0.25	2.1	19.6	2.27	2.57	0.34	0.03	1.5	0.82
SD	0.22	0.04	2.18	5.9	6.5	4.1	0.06	0.5	3.42	1.48	1.7	0.14	0.02	0.8	0.46
SE	0.05	0.01	0.48	1.2	1.3	0.8	0.01	0.1	0.7	0.3	0.34	0.03	0.004	0.2	0.09

BD- Bulk density, AP- available phosphorus, TN- total nitrogen, OC- organic carbon, CEC- cation exchange capacity, Ac- Exchangeable acidity and exAl-Exchangeable Aluminum.

Comparing lime requirement determination methods for acidic Nitisols

Modified Adams-Evans Buffer

The linear regression relationship between soil pH $_{(H2O)}$ and lime rate determined (t/ha) by modified Adams-Evans buffer (MAEB) was highly significant ($r^2=0.79^{***}$) (Figure 1). Lime recommendation could be made using this relationship for the analysis determined with use of the MAEB solution and soil pH (H_2O). The soil of the study area was the most buffered because of the soils CEC (20.5) and its clay textural class (Table 1).

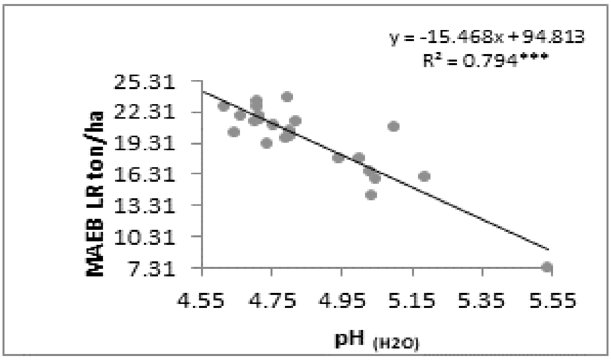

Figure 1. Regression equation on lime required for acidic Nitisols using MAEB

The linear regression relationship to raise soil pH to 6 was highly significant (Figure 1). Accordingly, 24.74 t/ ha lime was estimated (predicted) by regressing MAEB with pH (H_2O) initial, this amount of lime ($CaCO_3$) very high to amend the soil pH to 6.

Modified Mehlich Buffer

The linear regression relationship between soil pH $_{(H2O)}$ and lime rate determined (t/ ha) by modified Mehlich Buffer (MMB) was highly significant ($r^2=0.93^{***}$) (Figure 2. a). By regressing MMB determined LR with pH $_{(H2O)}$ 4.0 t ha^{-1} lime was estimated to bring the soil to target pH of 6.00.

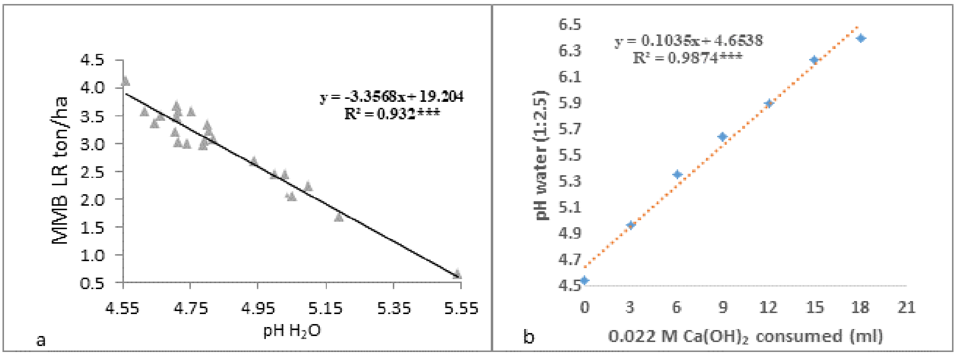

Figure 2. Regression equation for Lime required on Nitisols using (a) Modified Mehlich Buffer and (b) titration with 0.022M $Ca(OH)_2$.

Titration

Linear regression relationships between soil pH and 0.022 M $Ca(OH)_2$ consumed was highly significant (r^2=0.98***). The amount of lime estimated by this method is found to be 3.12 t/ha to adjust soil pH to 6 (Figure 2. b). The curve for the titration experiment was found to be linear curve; this was also supported by the work of Magdoff and Bartlett (1985) who indicated that the titration curves of acid surface soils are approximately linear. Furthermore, Weaver *et al*. (2004) found that the titration data of pH vs. added base were described well by a linear equation in the pH range of 4.5 to 6.5 for a group of soils from the coastal plain of Georgia.

Validation of different methods by incubation

The validation of MAEB by soil lime incubation revealed that all the proportions taken from the MAEB 24.74 t/ha (50, 100, 150, and 200%) took the soil above target pH 6.0. Even 50% (12.37 t/ha) of the predicted amount when tested by the incubation brought the soil pH from 4.88 to 7.42 (Figure 3.a). Warman *et al*. (2000) who evaluated the use of Adams Evans, SMP, and Mehlich buffers for determining the LR of Canadian soils also reported similar finding and found Mehlich buffer the most appropriate, whereas Adams Evans and SMP methods overestimated the LR, compared with the LR from greenhouse incubations. Fox (1980) who evaluated the Adams Evans method and concluded that it tended to overestimate LR of soils reported similar finding.

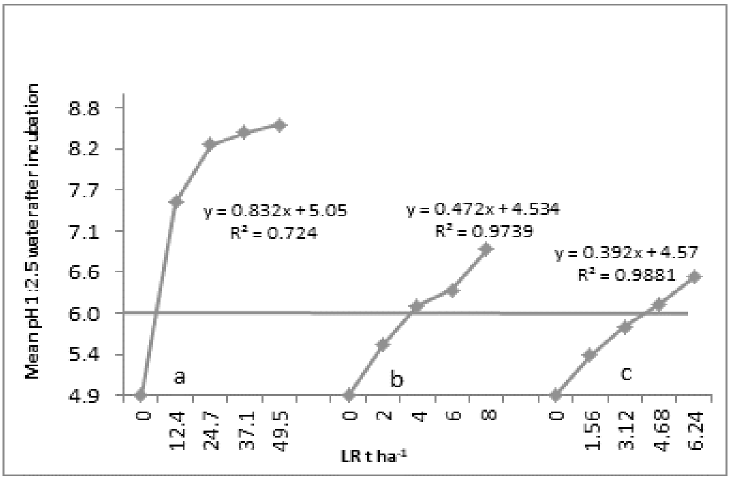

Figure 3: Mean pH for LR validated by incubation at (50, 100, 150 & 200%) for the rates determined by a-MAEB, b-MMB and c-titration by 0.022 M $Ca(OH)_2$ in the laboratory.

The result from validation of MMB by soil lime incubation revealed that the 100% of the MMB predicted LR (4 t/ha) brought the soil pH from 4.88 to 6.10. In the same way 50% of the MMB predicted (2 t/ha) brought the soil pH from 4.88 to 5.58 (Figure 3. b). In conformity to this work, different studies showed MMB to be the best LR predictor as compared to other buffer methods. Wolf *et al*. (2008) compared the SMP buffer with MMB and concluded that the MMB is a better predictor of LR and feasible alternative to the SMP buffer for determining LR on acidic soils of the Northeast and other regions of the United States. Similarly, Manjula *et al*. (2012) evaluated MMB and Sikora buffer as alternative to Modified Woodruff buffer for determination of lime in Missouri soil and found MMB the best predictor of lime rate. Dietzel *et al*. (2009) evaluated predictors of lime needs for pH and aluminum management in New York agricultural soils using exchangeable acidity SMP buffer, Mehlich buffer, and MMB test methods and found the MMB to be an acceptable replacement for the exchangeable acidity method.

Validation of the titration method by soil lime incubation to see whether it takes the soil to pH 6.0 revealed that the 100% of LR predicted by titration (3.12 t/ ha) brought the soil pH from 4.88 to 5.82, while 50% (1.56 t/ ha) of predicted LR brought the soil pH from 4.88 to 5.42 (Figure 3. c).

The linear regression relationship of the three methods is indicated on Figure 4 a-c. The linear regression relationship to raise the soil pH to 6.0 between pairs of lime rate requirement determination methods (MAEB-MMB (r^2=0.83***); MAEB- titration (0.022 M $Ca(OH)_2$) (r^2=0.79***) and MMB-titration (0.022 M $Ca(OH)_2$) (r^2=0.93***) were highly significant. The MMB and titration methods showed the highest regression (r^2=0.93) and were found to be better predictors of LR than MAEB to bring soil pH to the target pH of 6.0.

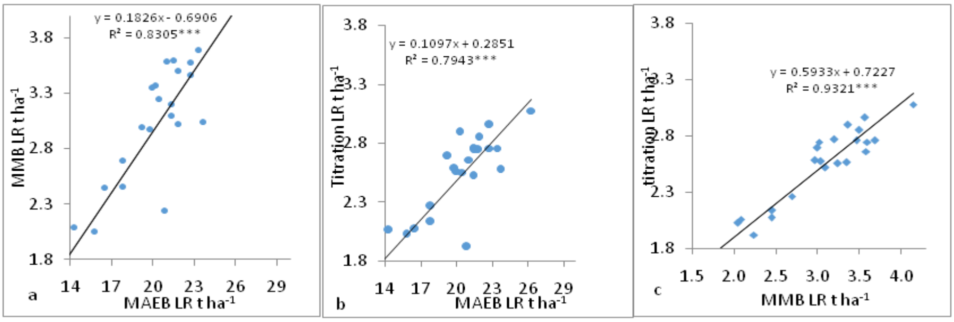

Figure 4. Functional relationships between MMB with Titration (a), MAEB with MMB (b) and MAEB with titration (c)

Conclusion

The MAEB, MMB and titration with 0.022 M $Ca(OH)_2$ methods predicted the lime requirement at the rate of 24.7, 4.0, and 3.12 t/ha respectively. The MMB and titration methods predicted the LR almost in approaching rate. The validation of the methods by soil lime incubation also revealed that the MMB and titration estimated the lime rates in the range affordable to the farmers who produce crops on Nitisols. Hence, areas covered with Nitisols can use the Modified Mehlich Buffer or titration to determine the lime rates required to amend their soils. However, incubation in the laboratory can't be real representative to validate the lime rates as it is performed under controlled temperature with moisture condition, therefore field calibrations are required using crops soil pH requirements before these tested methods are taken the best methods to amend the acidic Nitisols to pH 6.0.

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References

Achalu Cimidi, Heluf Gebrekidan, Kibebew Kibret, Abi Tadesse. 2012. Response of barley to liming of acid soils collected from different land use systems of Western Oromia, Ethiopia. J. Bio. div. Environ. Sci. 2(7):1-13.

Amsalu Akililu, L Stroosnijder and JD Graaff. 2007. Long-term dynamics in land resource use and the driving forces in the Beressa watershed, highlands of Ethiopia. Journal of Environmental Management 83: 448-459.

Athanase Nahusenay, R Vickya, MN Jayne, and H Sylvestre. 2013. Soil acidification and lime quality: sources of soil acidity, its effects on plant nutrients, efficiency of lime and liming requirements. *Agricultural Advances* 2(9) 259-269. ISSN 2251-7820

Bache BW. 1988. Measurements and mechanisms in acid soils. Communication in Soil Sci Plant Anal. 19:775-792.

Baker AS and YM Chae. 1977. A laboratory quick test for predicting lime requirement of acid mineral soils. Tech. Bull. 88. Washington Agric.Exp. Stn., Pullman.

Barrow NJ and VCCox. 1990. A quick and simple method for determining the titration curve and estimating the LR of soils. Austri. J. Soil Research: 28:685-694.

Behailu Kassahun. 2015. Soil Fertility Mapping and Fertilizer Blending. *Agricultural Transformation Agency* (ATA) report accessed at https://agriprofocus.com/upload/Soil_Fertility_Mapping_and_Fertilizer_blending1448614802.pdf

Berhanu Debele, 1980. The physical criteria and their rating proposed for land evaluation in the highland region of Ethiopia. Land Use Planning and Regulatory Department, Ministry of Agriculture, Addis Ababa, Ethiopia.

Bolan NS, DCAdriano, and D Curtin. 2003. Soil Acidification and Liming Interactions with Nutrient and Heavy Metal Transformation and Bioavailability. Advances in Agronomy, Volume 78.

Bouyoucos GJ. 1962. Hydrometer Method Improvement for Making Particle Size Analysis of Soils. *Agron. J.*, 54: 179-186.

Bray RH and LT Kurtz. 1945. Determination of Total, Organic and Available Phosphorus in Soils. *Soil Sci. J.*, 59(1): 39-45.

Bremner JM and CSMulvaney. 1982. Nitrogen total. p. 595-642. In A.L. Page *et al.* (ed.) Methods of soil analysis. Part 2. Chemical and Microbiological properties. SSSA, Madison, Wisconsin.

Dietzel K, Q Ketterings, and R Rao. 2009. Predictors of lime needs for pH and aluminum management for New York agricultural soils. Soil Science Society of America Journal 73:443–448.

Dunn, L.E. 1943. Lime requirement determination of soils by means of titration curves. Soil Sci. 56:341-351.

Fageria NK, VC Baligar. 2003. Fertility Management of Tropical acid soils for sustainable crop production. In: Rengel Z (ed), 'Handbook of soil acidity' Marcel Dekker, New York. pp. 359- 385.

FAO (Food and Agriculture Organization). 2006. Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome.

Farhoodi A, DR. Coventry 2008. Field crop responses to lime in the mid-north region of South Australia. Field Crops Res. 108:45-53.

Farina MPW and P Channon 1991. A Field comparison of lime requirement indices for maize. Plant Soil 134: 127-135.

Fox RH. 1980. Comparison of several lime requirement methods for agricultural soils in Pennsylvania. Commun. In soil sci. and plant anal. 11(1):57-69.

George E, R Sommer, and J Ryan. 2013. Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North. Africa region. International Center for Agricultural Research in the Dry Areas (ICARDA)

Geremew Taye, Ayalew Adella and Getachew Alemu. 2015. Response of Potato (*Solanium tubersum* L) to Potassium Fertilizer on Acid Soils of Welmera and Gumer Woredas, in the Highlands of Ethiopia, Journal of Biology Agriculture and Health Care. Vol 5 No 17 (2015) pp 156-160.

Getachew Alemu, Temesgen Desalegn, Tolessa Debele, Ayalew AdelLa, Geremew Taye, and Chelot Yirga .2017. Effect of lime and phosphorus fertilizer on acid soil properties and barley grain yield at Bedi in Western Ethiopia. African Journal of Agricultural Research. Vol. 12(40), pp. 3005-012, 5 October, 2017 DOI: 10.5897/AJAR2017.12562 Article Number: 945989266219 ISSN 1991-637X.

Gobena Huluka. 2005. A Modification to the Adams-Evans Soil Buffer Determination Solution. *Communications in Soil Science and Plant Analysis,* 36: 2005–2014, Taylor & Francis, Inc.

Hazelton P and B Murphy. 2007. Interpreting soil test results. What do all the numbers mean? *CSIRO Publishing, Victoria*.

Hoskins B. 2005. Modification of the Mehlich buffer test for Maine. Soil Science Society of America Abstracts, ASA-CSSA-SSSA International Meetings, November 6–10, 2005, Salt Lake City, Utah.

Jones, J.B., 2003. Agronomic Handbook: Management of Crops, Soils, and Their Fertility. CRC Press LLC, Boca Raton, FL, USA. 482p.

Landon JR. 1991. Booker Tropical Soil Manual: A hand book for soil survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. 474p. OR John Wiley & Sons Inc., New York.

Liu M, DE Kissel, PF Vendrell, ML Cabrera. 2004. Soil LR by direct titration with calcium hydroxide. *Soil Sci Soc Am J*. 68:1228–1233.

Liu M, DE Kissel, ML Cabrera, and P F Vendrell. 2005. Soil lime requirement by direct titration with a single addition of calcium hydroxide. Soil Science Society of America Journal 69:522–530.

Magdoff FR and RJ Bartlett. 1985. Soil pH buffering revisited. Soil Sci Soc Am Proc. 49:145–148.

Malcolm ES and DN Andrew. 2003. Soil acidification: the world story. *In*: Zdenko R (ed.) Handbook of Soil Acidity. Marcel Dekker, New York, pp 1-28.

Manjula VN, Y Sun and PC Scharf. 2012. Evaluation of Modified Mehlich and Sikora Buffer Methods as an Alternative to Modified Woodruff Buffer in Determining Lime Requirement for Missouri Soils, Communications in Soil Science and Plant Analysis, 43:1-2, 496-505, DOI: 10.1080/00103624.2012.641843

McLean EO, JF Trierweiler, and DJ Eckert. 1977. Improved SMP buffer for determining lime requirements of acid soils. Communications in Soil Science and Plant Analysis 8 (8):667–675.

Mehlich A. 1976. New buffer pH method for rapid determination of exchangeable acidity and LR of soil. Commun *Soil Sci Plant Anal* 7(7):637-652.

Mekonnen Asrat, Heluf Gebrekidan, Y Markku, Bobe Bedadi, and Wakene Negassa. 2014. Effect of integrated use of lime, manure and mineral P fertilizer on bread wheat (*Triticum aestivum*) yield, uptake and status of residual soil P on acidic soils of Gozamin District, northwestern Ethiopia. J. Agriculture, Forestry, and Fisheries. 3(2): 76-85. doi: 10.11648/j.aff.20140302.15.

Mesfin Abebe. 2007. Nature and management of acid soils in Ethiopia. Addis Ababa, Ethiopia.

Okalebo JR, KW Gathua, and PL Womer. 2002. Laboratory methods of sol and plant analysis: A working manual, 2nd edition. TSBF-CIAT and SACRED Africa, Nairobi, Kenya. 128p.

Osundwa MA, JR Okalebo, WK Ngetich, JO Ochuodho, CO Othieno, B Langat, and VS Omenyo 2013. Influence of Agricultural Lime on Soil Properties and Wheat (*Triticum aestivum L.*) Yield on Acidic Soils of Uasin Gishu County, Kenya. American Journal of Experimental Agriculture 3(4): 806-823.

Pantelis EB, N Moustakas and ALTsakalidi. 2013. A rapid procedure to calculate lime requirements based on single titration with base, Archives of Agronomy and Soil Science, 59:2, 317-325.

Rowell DL. 1994. Soil Science: Methods and Applications. Addison Wesley Longman Singapore Publishers P. Ltd., England, UK. 350p.

Schlede H. 1989. Distribution of acid soils and liming materials in Ethiopia, Institute of Geological Surveys: Industrial Mineral Division. Note. No.326, Addis Ababa, Ethiopia.

Slattery WJ, DR Coventry. 1993. Response of wheat, triticale, barley, and canola to lime on four soil types in north-eastern Victoria. Australian Journal of Experimental Agriculture 33: 609-618.

Sonneveld BGJS and MA Keyzer, 2003. Land under pressure: Soil conservation concerns and opportunities for Ethiopia. *Land degradation and development*. 14: 5-23.

Sumner ME, AD Noble. 2003. Soil acidification: the world story. In: Rengel, Z., (ed.) Handbook of soil acidity. Marcel Dekker, New York, pp. 1- 28.

Temesgen, Desalegn, Getachew Alemu., Tesfu Kebede., Tolessa Ddebele, and Mesfin, Tadese., 2011. Past and present soil acidity management research in Ethiopia. A review. Paper presnted at the '2nd National Soil and Water Management Workshop', 28 -31 January 2011, Addis Ababa, Ethiopia.

Tesfaye Dejene, Tamado Tana, and Elias Urage. 2016. Response of Common Bean (*Phaseolus vulgaris* L.) to Application of Lime and Phosphorus on Acidic Soil of Areka, Southern Ethiopia. Journal of Natural Sciences Research. Vol.6, No.19, 2016.

Van Reeuwijk LP. 1992. Procedures for Soil Analysis, 3rd Ed. International Soil Reference and Information Center (ISRIC), Wageningen, the Netherlands. 34p.

Walkley A and IA Black. 1934. An Examination of the Degtjareff method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method. Soil Sci., 37: 29-38.

Warman PR, IY Walsh, and AV Rodd. 2000. Field testing a lime requirement test for Atlantic Canada, and effect of soil pH on nutrient uptake. Communications in Soil Science and Plant *Analysis* 24:2163–2169.

Weaver AR, DE Kissel, F Chen, LT West, W Adkins, D Rickman, and JC Luvall. 2004. Mapping soil pH buffering capacity of selected fields in the coastal plain. Soil Sci Soc Am J. 68:662–668.

Wolf A and D Beegle. 2005. Evaluation of Mehlich buffer pH method in Pennsylvania. In *Symposium on Update of Soil Liming Recommendations: Soil Science Society of America annual meetings abstracts*. Madison, Wisc: ASA, CSSA, and SSA.

Wolf A, D Beegle, and B Hoskins. 2008. Comparison of Shoemaker–McLean–Pratt and modified Mehlich buffer tests for lime requirement in Pennsylvania soils. *Communications in Soil Science and Plant Analysis* 39:1848–1857.

Woubshet Demissie, Selamyihun Kidanu, Tolera Abera, and CV Raghavaiah. 2017. Effects of Lime, Blended Fertilizer (NPSB) and Compost on Yield and Yield Attributes of Barley (*Hordium Vulgare* L.) on Acid Soils of Wolmera District, West Showa, Ethiopia. Ethiopian .J. Appl. Sci. Technol. Vol.8 (2): 84-100.