FIELD CALIBRATION OF LIME REQUIREMENT SOIL TESTS FOR ACID NITISOLS AND FERRALSOLS OF KENYA FOR THE DEVELOPMENT OF A QUICK LIME ESTIMATION TEST KIT

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Abstract

The beneficial effects of liming acid soils (pH< 5.5) have been proven beyond doubt. However the problem of how much lime to apply has always faced farmers. With the main objective to assess the lime estimation methods currently in use in the world and select one that would be suitable in Kenya for development of a quick lime estimation kit lime rates of 0, 0.5, 1.0, 2.4, 6, and 8 t ha^{-1} were incorporated to 0-15cm soil depths at various field experimental 8 sites in the tea growing acid Nitisols of Central Kenya and in the acid Ferralsols of Western Kenya using maize as a test crop. Soil samples were collected for each liming level after 3 months for laboratory lime estimations using Ca(OH)$_2$ titration, dolomitic lime - soil incubation for 7 days, and with a range of buffer methods that included SMP single and double-SMP buffer methods, Yuan double-buffer method, Mehlich single buffer method, modified Mehlich single buffer method, and Adams and Evans buffer method. The optimal field lime requirement for maize was 1 t ha^{-1} and 7 t ha-1(pH 6.2 and pH 5.5) in Ferralsols and Nitisols respectively, indicating the great need for accurate lime requirement prediction. The Ca(OH)$_2$ titration gave a high correlation (r^2= 0.87) with field lime requirement. Soil-lime incubation gave a very low correlation (r^2 = 0.007) with field lime requirement. Among the buffer methods, the modified Mehlich buffer method gave high and consistent correlations for parameters against the field lime requirements to pH 5.5. The SMP double buffer, the Yuan double buffers and the modified Mehlich buffer methods gave the least % deviations from the field lime requirements. However because of the ease of preparation and the absence of harzadous chemicals in the modified Mehlic buffer, the latter is recommended in the preparation of the quick lime estimation test kit. Soil pH gave a high correlation (r^2 = 0.98 (Nitisols) and 0.7 (Ferralsols) with field lime requirement and is recommended for use in lime estimations especially in Nitisols.

Key words: Buffer pH, Ca(OH)$_2$ titration, field trials, lime-soil incubation, lime requirement

1.0   Introduction

Acid soils are characterised by pH of less than 5.5 and low chemical fertility (Summer, 2005). The low pH results to toxicity of aluminium (Al) and or manganese (Mn) while calcium (Ca), magnesium (Mg), phosphorus (P) and/or molybdenum (Mo) deficiencies are the main aspects of chemical infertility (Von Uexküll and Mutert 1995, Summer, 2003). In addition, more than 95% of these soils suffer from subsoil acidity that limits the penetration of roots to deeper layers where substantial moisture reserves are stored (Summer, 2005). Acid soils occupy approximately 30% or 3950 million ha of the world's ice-free land (FAO, 1991, Von Uexküll and Mutert, 1995) and more than 2 billion people rely on these soils for their sustenance in Latin America, sub-Saharan Africa, and Southeast Asian Nations. Consequently, the acid soils, which are major limitations to crop production, directly impact the health and nutrition of multitudes of people who live in both rural and urban areas. In Kenya, acid soils cover approximately 10% or 5.5 million ha and are mainly found in areas receiving an annual rainfall average of 1000-2700 mm (Wokabi, 1987). Therefore majority of acid soils would be suitable for agriculture except for their acidity and related chemical constraints.

The main causes of the acidity in Kenyan soils are mainly due to weathering or amorphous mineralogy. Moreover these soils have been under continuous crop cultivation and mineral fertilization since their occupation by the white settlers in the beginning of 20th century and land adjudication in 1960s. They are therefore becoming more acid with time.

Lime is applied to acid soil with the primary aim of raising pH so as to reduce Al or Mn toxicity. However over-liming may reduce availability of micronutrients while under-liming will be a waste of money (Sanchez, 1976). Whatever the objective, there needs to be a sound basis for determining the correct amount of lime to apply because soils differ in their initial pH, Al saturation levels and pH buffering capacities. This is particularly more critical in highly weathered soils in which there can be a serious detrimental effect from over-liming (Kamprath, 1971; Sanchez, 1976).

Direct titration of soil acidity by a base to estimate liming requirement poses a problem of how to complete the titration in a reasonable time and yet add the base sufficiently slowly so that it is neutralized without

subjecting soil to a much higher pH than is encountered in normal liming practice. Buffers permit neutralization of soil acidity at relatively low and nearly constant pH. For quick estimation of soil liming requirements, single-buffer methods (Shoemaker et al., 1961) and double-buffer methods (Yuan, 1974; McLean et al., 1978) are currently in use. Other methods commonly used to determine lime requirement of an acid soil are (i) application of increasing levels of lime to a number of samples of a moist soil followed by determination of the extractable Al which is related to the lime required to precipitate it (Aitken et al., 1995) (ii) incubation of a wet soil with various levels of lime and derivation of a calibration curve of pH against lime, and (iii) Titration of a soil with calcium hydroxide solution and subsequent determination of equivalent amounts of lime especially when calcium oxide is the liming material (Chapman and Pratt, 1961). However, these methods must be evaluated and calibrated against lime requirements determined at various pH levels by field trials (Alley and Zelazny, 1987). For Kenya's acid soils these methods have neither been evaluated (lime requirement) nor been calibrated as per pH target for maximum crop yield. The purpose of this study was to evaluate some laboratory methods for estimation of liming requirements field lime needs and select the most suitable one for development of a Quick Liming Test Kit (QLTK) as a contribution towards food security Kenya's highlands where acid soil are prevalent.

2.0   Materials and Methods
2.1   Soil Sampling for Chemical Analyses
A reconnaissance sampling of soils identified in the exploratory soil map of Kenya (Sombroek et al., 1980) as acid was done in 2007. Some important chemical characteristics of representative acid soils of Kenya are indicated in table 1. Soil was sampled from representative sites at 0-15 cm depth for analysis of pH in water and salt solutions (1: 2.5 soil: water, pH 1MKCl and 0.01 M $CaCl_2$), organic carbon, effective cation exchange capacity (ECEC), base saturation (BS) KCl extractable Al (Hinga et al., 1980).

2.2   Laboratory Methods for Predicting Lime Requirement (LR)
2.2.1 Soil pH
Soil samples were air-dried, sieved through 2 mm sieves and mixed. Each soil sample from the trial site and surrounding regions with similar soil types were analyzed for pH (1:2.5 soil: water,unless when the specific experiment required different ratios) after 30 min shaking. Also pH was also measured in 1 M KCL and 0.01 $CaCl_2$. The pH values were regressed against field lime requirements to target pH of 5.5.

2.2.2 Extractable Al
Aluminium (Al) was extracted using with 1:10 soil/ 1M KCl solution through shaking for 1h. It was then determined spectrophotometrically by the aluminon method (Bloom et al., 1978). The amount of Al extracted by 1M KCl for each experimental site was converted to lime and related to the field lime requirement to pH 5.5.

2.2.3 Reaction of soil with $Ca(OH)_2$
Soil in a 1:2 soil/water ratio was titrated with graded amounts of $Ca(OH)_2$ solution and left for three days for reaction and pH stabilization. A curve of $Ca(OH)_2$ versus pH was plotted and equivalent amounts of dolomitic lime per hectare to pH 5.5 was then calculated.

2.2.4 Reaction with Liming Material
25 g soil in conical flasks was added graded amounts of dolomitic lime and thoroughly mixed. It was then wetted with 15 mL of water, stirred and left for 7 days at room temperature. Water was then added to the soil to make the ratio of soil: solution 1:2.5. After shaking, the pH was measured and a calibration curve was plotted. The amount of lime per hectare required to pH 5.5 was then calculated.

2.2.5 Mehlich Single-buffer method having an initial pH of 6.6
10 mL water will be added to 10 g soil and allowed to equilibrate for 30 minutes. pH (H_2O) will then be measured by pH meter. Thereafter 10 mL of buffer solution will then be added and the suspension shaken for 10 minutes and then allowed to equilibrate for a further 50 min before measuring the soil :buffer pH. The exchangeable acidity was then calculated. The L.R was then calculated on the basis of a combination of buffer exchangeable acidity (Ac), the target pH for the crop, and the calcium carbonate equivalence (CCE) of the lime (Mehlich, 1976)

2.2.6 SMP Single-buffer method with an initial pH of 7.5 (Shoemaker et al., 1961)

10 mL water were added to 10 g soil and allowed to equilibrate for 30 minutes. pH (H_2O) was then be measured by pH meter. Thereafter 10 mL of buffer solution were added (1:2 soil:buffer ratio) and the suspension was shaken for 15 min followed with 15 min standing time. pH was then measured using a pH meter and LR determined as per Shoemaker et al. 1961.

2.2.7 SMP double-buffer method with initial pH values of 7.5 and 6.0 (McLean et al., 1978)

The buffer composition was as in immediate above but then aliquots of HCl were added to decrease the pH of buffer to 6.0 so as to create two buffers; each of the two buffers were treated with soil as in immediate above. The LR was then calculated as per McLean et al. (1978).

2.2.8 Yuan Double-Buffer Method with Initial Ph Value of 7.0 and 6.0 (Yuan, 1974)

The buffer solution composition was as for The pair mixture of 1:10 soil : buffer using pH 6 and pH 7 buffers respectively were then shaken for 1 h before pH measurement. The LR was then computed as per the formula of Yuan (1974).

2.2.9 Adams and Evans single buffer method with an initial pH value of 8.0 (Adams and Evans, 1962)

The buffer solution was constituted as per Adams and Evans (1962) its pH adjusted to pH 8.00 using either dilute KOH or HCl. A pH of a suspension of 20 g soil and 20 mL water (mixed for 30 secs and allowed to stand for 30 min) was measured with a pH meter. Then 20 mL of buffer solution were added, stirred for 30 secs and pH again determined. The exchangeable acidity and liming requirement were then be calculated as per Adams and Evans (1962).

2.2.10   Field Liming Trials

At each site, representing a sample of the acid soils of Kenya Ferralsols (rhodic and orthic), and Nitisols (ando-humic) various rates of lime at varying rates of 0, 0.5, 1.0, 2.4, 6, and 8 t ha was broadcast on to 20 m x 6 m plots and mixed into 0-15 cm of soil at least 4 weeks prior to planting. Five and two experimental sites represented the Nitisols and ferralsols respectively. Soil samples were collected from each plot before liming and at three months after liming for measurement of pH and other chemical analysis. A randomised block design with four replications of each treatment was used at each site. The maize hybrid variety planted for each site was the recommended one for the area. At maize milk stage cob diameters and lengths data were taken from the middle rows. At complete maturity, the grain was harvested and weighed to get the maize yield in t ha^{-1}, after adjustment to 13% moisture content.

2.3   Data Analysis

Lime requirements (LR) were determined for all methods and calculated as t ha $^{-1}$ to a depth of 15cm at respective bulk soil densities. Linear regression functions and correlation coefficients (R^2) between various laboratory lime estimation methods and field LR at various target pH values were then derived. The method that would give the highest correlation and least deviation from the field lime requirement would be selected for use in the Nitisols and ferralsols of Kenya and for development of a Quick Lime Test Kit.

3.0   Results
3.1   Soil pH

The soil pH and field lime requirement gave moderate to high linear correlations in Nitisols and ferralsols (r^2=0.66) and Nitisols (r^2=0.99; and moderate one for Ferralsols (r^2= 0.67) . The curvilinear functions had even higher correlations for the same (Fig.1).
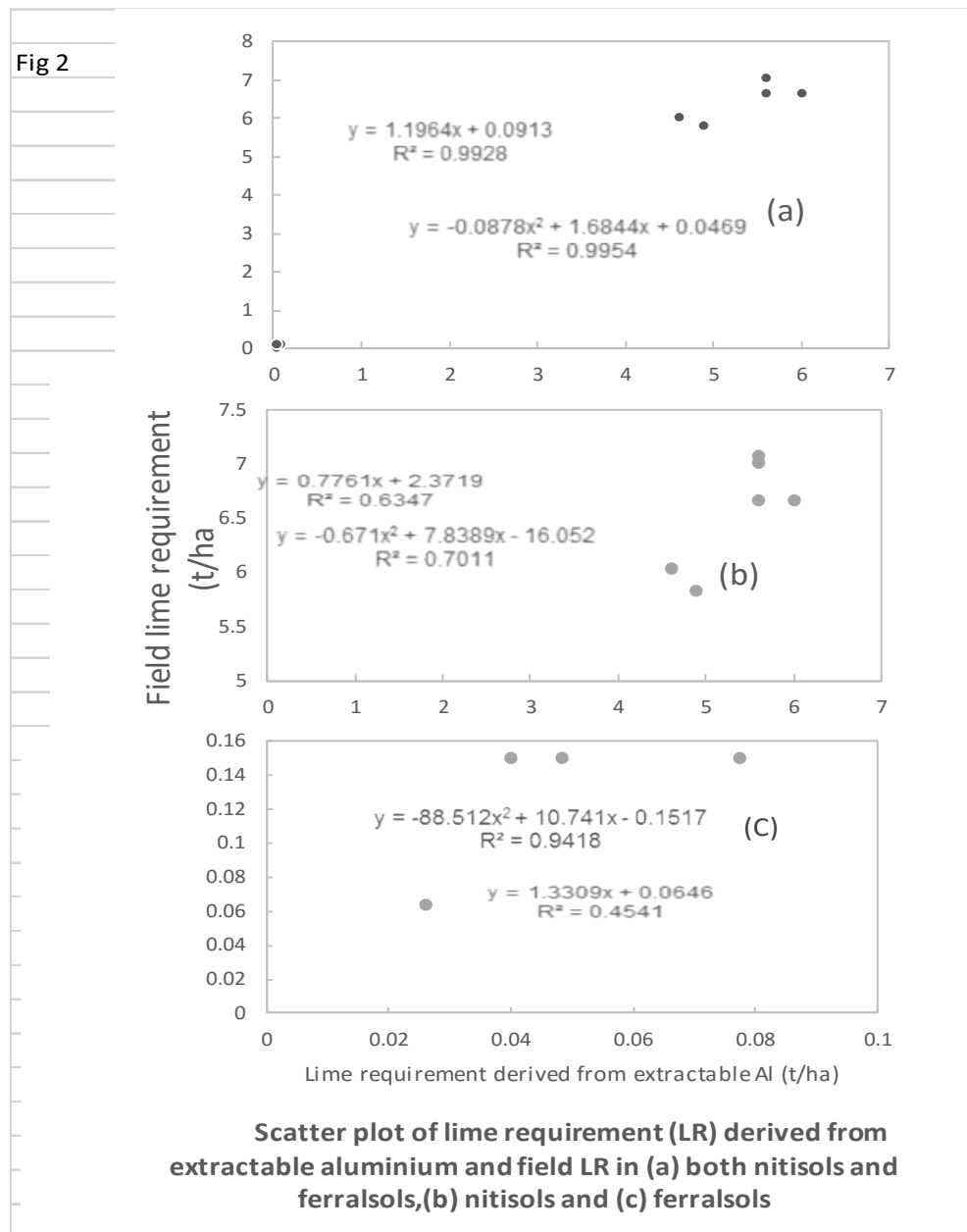
Figure 1
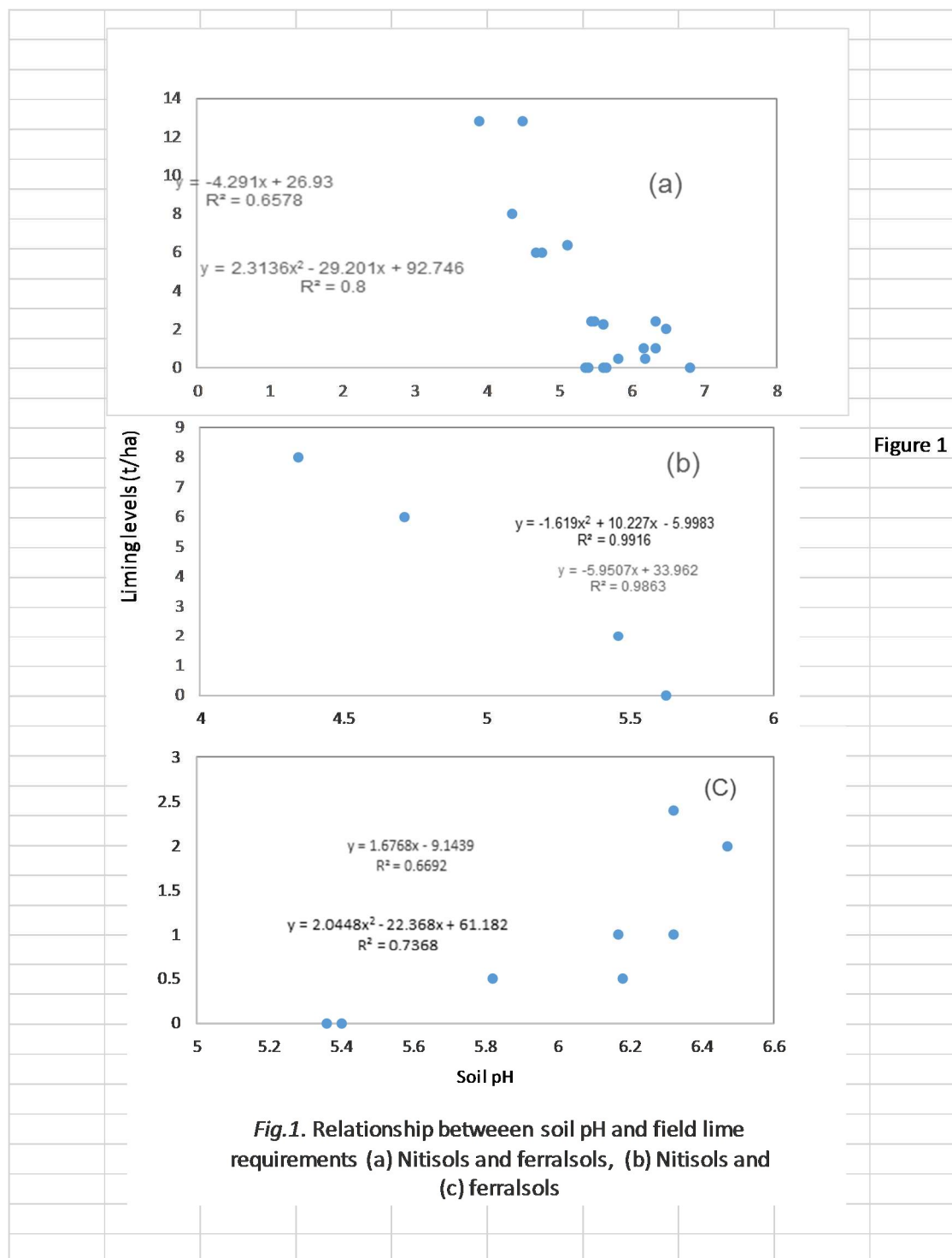
Fig.1. Relationship betweeen soil pH and field lime requirements (a) Nitisols and ferralsols, (b) Nitisols and (c) ferralsols

3.2 Extractable Aluminium

The ferralsols of Western Kenya had low aluminium saturation as compared with those on Mt. Kenya and Aberdares slopes (Table 1). Figure 2 shows the relationship between the lime estimation with extractable Al and that from field trials. The lime requirement was well correlated in linear relationship for both soils in eastern and western Kenya soils. The correlations were moderate for Nitisols and low for Ferralsols alone (0. 64 and 0.45 respectively). However curvilinear relationships displayed high correlations in all cases. The lime requirements from field trials to pH 5.5 were higher than those estimated from extractable Al by a factor of 1.2 to1.3 (15-20%) and 2 to 3 (50-70%) for East of Rift-valley and Western Kenya soils respectively.
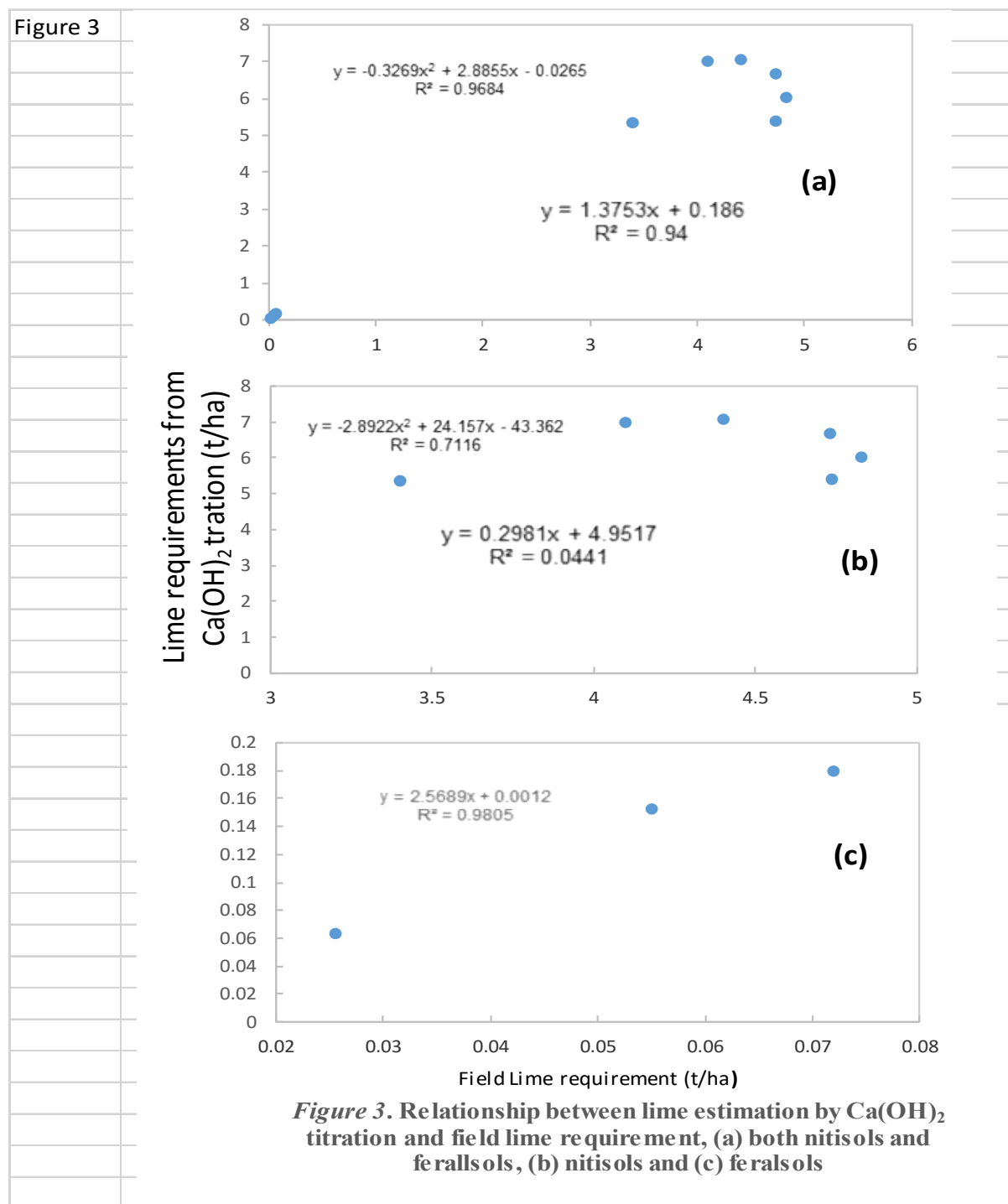
Table 1: Chemical properties of representative acid soils of Kenya

County	Classification	pH Water (1:2.5)	pH 1NKCl	pH 0.01CaCl2	Exchangeable cations (cmoles+/Kg)					CEC(Sum of cations)	BS%	Al Sat.%	O.C%
					Na	K	Ca	Mg	Al				
Uashin Gishu	L24 Rhodic Ferralsol	5.06	4.32	4.59	0.43	0.69	4.34	1.88	0.16	7.50	30.49	2.13376	1.63
Uashin Gishu	L24 Rhodic Ferralsol	5.03	4.16	4.47	0.28	1.39	3.46	2.34	0.27	7.74	35.33	3.49	1.53
Uashin Gishu	L24 Rhodic Ferralsol	5.34	4.33	4.67	0.31	1.57	3.72	2.90	0.07	8.57	39.41	0.82	1.91
Uashin Gishu	L24 Rhodic Ferralsol	5.65	4.15	4.34	0.50	1.10	2.52	1.48	0.42	6.02	28.72	6.97	1.63
Uashin Gishu	L24 RhodicFerralsols	5.28	4.26	4.5	0.38	1.21	3.06	2.34	0.24	7.23	36.98	3.32	4.2
Uashin Gishu	L24 R.ferralsol	5.63	4.55	4.87	0.28	0.94	6.52	1.42	0.06	9.22	23.10	0.65	4.57
Uashin Gishu	Uh11 Humic Nitisol	5.11	4.18	4.45	0.64	0.70	3.82	3.72	1.12	10.00	42.36	11.20	4.4
Nandi	Uh1 Humic Cambisols	5.86	4.73	5.08	0.40	1.52	12.36	5.83	0.08	20.18	43.15	0.39	5.4
TransNzoia	U117 Rhodic Ferralsol	5.78	4.66	4.78	0.26	0.49	2.94	1.28	0.05	5.03	29.23	0.99	1.33
TransNzoia	U117 Rhodic Ferralsol	5.37	4.39	4.46	0.54	0.35	2.34	1.25	0.04	4.52	30.91	0.89	2.08
Bungoma	U1 15 Rhodic Ferralsols	5.61	4.56	4.73	0.28	0.39	3.92	1.61	0.15	6.35	29.99	2.36	1.83
Bungoma	U1 15 Rhodic Ferralsols	5.38	4.47	4.55	0.38	0.39	2.72	1.28	0.27	5.05	28.94	5.35	2.02
Busia	U1 11 Orthic Ferralsol	5.5	4.61	4.43	0.57	0.30	1.86	0.79	0.46	3.98	22.58	11.55	1.47
Kakamega	Um 10 Humic Acrisols	6.34	5.24	5.19	0.37	0.32	4.72	3.26	0.05	8.71	42.81	0.57	2.46
Kakamega	Um 10 Humic Acrisol	6.68	5.53	5.64	0.30	0.39	5.08	1.28	0.06	7.11	23.83	0.84	1.86
Kakamega	Uh 18 Ferralo-Chromic/Orthic Acrisol	6.18	5.19	5.11	0.59	0.43	3.94	1.74	0.03	6.74	30.86	0.45	2.3
Kakamega	Uh 18 Ferralol-Chromic/Orthic Acrisol	6.33	5.17	5.18	0.57	0.33	3.5	1.48	0.04	5.92	29.41	0.68	1.91
Kericho	R9 Humic Cambisols	5.97	4.91	4.83	0.31	0.31	2.42	0.92	0.04	4.00	26.07	1.00	2.91
Kericho	R9 Humic Cambisols	5.83	4.9	4.82	0.31	1.12	2.84	2.01	0.38	6.66	34.43	5.71	5.44
Kericho	R9 Humic Cambisols	5.71	4.77	4.75	0.68	0.87	4.66	1.48	0.13	7.82	25.15	1.66	4.76
Kiambu	R1 Ando-humic Nitiso	5.28	4.26	4.61	0.66	1.47	2.36	2.24	1.70	8.43	31.06	20.18	1.94
Kiambu	R1 Ando-humic Nitisol	3.86	3.7	3.83	0.68	0.56	4.1	1.2	14	20.54	11.1823	68.1597	4.03
Nyeri	R1Ando-humic Nitisol	6.3	5.01	5.75	0.59	1.82	14	4.97	0.16	21.54	39.49	0.74	2.63
Nyeri	R2 humic Nitisol	5.36	4.61	4.65	0.61	2.39	2.74	2.44	8.50	16.67	20.35	50.98	5.72
Meru	R1 Ando-humic Nitisol	4.29	3.66	3.66	0.84	0.57	3.9	0.91	6.4	12.62	12.5208	50.7132	6.71
Embu	R1 ando-humic Nitisol	4.77	3.99	4.13	0.06	0.17	0.9	0.6	5.04	6.77	9.99263	74.4461	3.61
Embu	R2 humic Nitisol	4.51	4.3	4.29	1.34	6.11	0.27	3.75	7.4	18.87	27.5928	39.2157	3.36

Fig 2

In (a): $y = 1.1964x + 0.0913$, $R^2 = 0.9928$; $y = -0.0878x^2 + 1.6844x + 0.0469$, $R^2 = 0.9954$

In (b): $y = 0.7761x + 2.3719$, $R^2 = 0.6347$; $y = -0.671x^2 + 7.8389x - 16.052$, $R^2 = 0.7011$

In (c): $y = -88.512x^2 + 10.741x - 0.1517$, $R^2 = 0.9418$; $y = 1.3309x + 0.0646$, $R^2 = 0.4541$

Y-axis: Field lime requirement (t/ha)

X-axis: Lime requirement derived from extractable Al (t/ha)

Scatter plot of lime requirement (LR) derived from extractable aluminium and field LR in (a) both nitisols and ferralsols,(b) nitisols and (c) ferralsols

3.3　Ca(OH)₂ Incubation

The global lime requirement (for both nitisols and ferralsols) derived from $Ca(OH)_2$ gave moderate to very high correlation of determination against field lime requirements especially from curvilinear functions (Figure 3). However the coefficients of determination for soils in the east Rift valley were low to moderate high for curvilinear and linear functions respectively. To convert the lime requirement derived from $Ca(OH)_2$ to field lime requirements, mean multiplication factors of 1.7 and 2.5 for Nitisols of eastern Kenya and Ferralsols of Western Kenya were found.

Figure 3

Figure 3. **Relationship between lime estimation by** $Ca(OH)_2$ **titration and field lime requirement, (a) both nitisols and ferallsols, (b) nitisols and (c) feralsols**

3.4 Soil-lime Incubation

The linear relationships were very high (Fig.3) in both soils of eastern and western Kenya implying that the LR from lime incubation can be adjusted with multiplication factors with some degree of accuracy.

3.5 Buffer Methods
3.5.1 Buffer pH and Calculated Liming Requirement

The relationship between buffer pH and calculated liming requirements is shown in table 2. The single SMP buffer method gave the highest coefficient of determination (r^2=0.86).

Table 2. The relationship between buffer pH and calculated liming requirement

Method	R^2 to target pH of 5.5
Single SMP buffer	0.86
Mehlic single buffer	0.43
Modified mehlic	0.61
Adams and Evans buffer	0.72
Yuan double buffer	0.72
SMP double buffer	0.81

3.5.2 Buffer Methods and Lime Requirements
All the buffer methods presented here (Table 3) were correlated with field lime requirements.

The Yuan double buffer gave the highest correlations and least deviations from the field lime requirements. The modified Mehlich similarly performed well in all of the correlations from all the parameters assessed. There was not significant difference between single and double buffers. All the buffer methods overestimated except the Adam and Evans which underestimated the LR except in Nitisols where the overestimation was only 17%. The SMP and Mehlich single buffers greatly overestimated the LR except for Nitisols.

4.0   Discussion and Conclusions
Although yield data is not presented in this paper (presented elsewhere), which is confined to the efficacy of laboratory methods in estimation of lime requirements, the response to liming of maize could be described as dramatic in the acid Nitisols of East of Rift Valley but low in the Ferralsols of West of Rift valley. Past and this work (Tessens and Shamshuddin,1982; Mugai et al.,2008) has shown that highly weathered strongly acid soils rarely benefit from liming above pH 5.5. However, this generalization needs to be re-visited in the plinthic Ferralsols (orthic Ferralsols with petroferric phase) (Somroek, et al., 1980; FAO-UNESCO, 1988) that have pH between 5.3-5.4 and very low buffering capacity where liming to pH above 6.0 gave a positive yield response.

Lime requirement depends on both initial soil pH and soil acidity buffer capacity. However, pH can be used to predict lime requirement within a certain soil type. More surprising to the author in a study of Australian soils of varying characteristics, Aitken got moderate correlation of (r^2=0.59) to target pH 5.5. This agrees with this study.

In the acid soils like the one in this study, aluminium is one of the main limitations to plant growth and therefore liming of soils has an objective of neutralizing this toxic element. The use of extractable Al was used by Kamprath (1984) to estimate the liming requirement. This extractable Al is then equated with lime being used and the latter correlated with lime from field trials to soil pH 5.5. The results agree with those of Aitken (1995) that extractable Al greatly underestimates liming requirements. The reason for this is that some acidity that is neutralized by lime originates from deprotonation reactions rather than wholly from Al (Gilman and Sumpter, 1986). The acid soils in the East of Rift-valley have much higher absolute lime requirements both from field trials and also that calculated from extractable Al mainly because of their lower pH, higher CEC and higher Al content (Table 1). The smaller difference between lime requirement from extractable Al and that from field liming trials in soil in the east of Rift-valley means that Al is the major contributor to acidity in those soils, implying that extractable Al can be used to estimate the liming requirements with a multiplication factor. However, the global relationship for both soils in east and west of rift-valley was exaggerated because of absent data over due to the large Al capacities of the two soils. This method, though laborious, is quite reliable in estimation of liming requirements (Follet, 1983), but was not yet tested on Kenyan soils.

The reasons for the underestimation of LR by Ca $(OH)_2$ incubation are not clear but was probably due to precipitation of the hydroxide by carbon dioxide to carbonates thus decreasing the reaction with the acid soil and or the incomplete equilibration between soil and $Ca(OH)_2$. However, the correlations of determination corroborated well with those obtained by Aitken (1995; R2= 0.84). The main disadvantage of soil - $Ca(OH)2$ equilibration   method is that the soil-lime mixtures must be incubated over several days to reach an equilibrium and thus the method is time - consuming and not suited for routine soil testing. However, the method suitable for estimating LR by non-soil scientists like farmers and extension workers in scantly equipped environments. The amount of lime needed to change soil pH varies with texture, cation exchange capacity and organic matter content and all this is related to the soil's buffer capacity. The method has been used successfully by Mugai et al (2008) to estimate the LR of a humic Nitisol in potted bean culture. Moreover, the

method has the advantage in that the grower can access the lime from the market or in store for the experiment

The lime estimation from lime incubation with soil was underestimated by 24%, 14% and 41% in both nitisols and Ferralsols, nitisols of eastern Kenya and Ferralsols of western Kenya respectively. The consequent multiplication factors for the same were 1.37, 1.16 and 1.73 respectively. The underestimation of LR by lime incubation is mainly attributed to shorter soil-lime incubation. Many workers have shown that equilibration of soil with lime is attained after 60 days (Godsey, et al., 2007; Lierop, 1983).

The relationship soil: buffer pH against field lime trials as a method of lime estimation is useful in single buffers but not in case of double buffers where two sets of pH levels are obtained. Aitken et al. (1995) only used this method with only single buffers and obtained high correlations of around r^2= 0.7. In this work no significant differences were found between coefficients of determination this method and the buffer calculated LR and the field LR. This means that method can as well substitute for the latter one.

Among the six buffers evaluated (Table 3) for the calculated LR and the field LR relationships, the modified Mehlich buffer method and the Yuan double buffer had the performers in respect to coefficients of determination and had the least deviations from the field lime requirements. The Mehlich buffer method specifically measures exchangeable acidity (H^+ and Al^{+3}) through exchange by the Ca^{++} that is present in the buffer. Thus the decrease in pH is linearly related to the exchangeable acidity. Since most of the acidity in the Nitisols and ferralsols of Kenya is due to exchangeable acidity the buffer seems appropriate. Another advantage of this buffer is the absence of harzadous chemicals. The modified mehlich was developed by to replace the Mehlich buffer (Mehlich, 1976) by replacing the toxic barium with Ca but still performing the same function. Adams and Evans method is premised on same principle. The latter buffer LR deviated by only 15% from field LR in Nitisols and shows it is also viable option for these soils. This work confirms what was observed by Aitken et al., (1995) that double buffers have little advantage over single buffer methods in lime predictions. However, the double buffers tended to have closer lime predictions of the Ferralsols due to the latter's very low buffering capacity. The low overestimation of LR by all buffer methods in Nitisols is probably due to their higher buffering capacity contributed to by the high organic matter content. The SMP buffer is has been shown to be inaccurate in poorly buffered soils that have a predominance of kaolinite and Al and Fe oxides like the Ferralsols and Nitisols in this study ((McLean, 1982; van Lierop, 1991). The buffer was also developed for soils with large lime requirements and might not be suitable for low buffered soils like the ones in the study.

In conclusion, the study has shown that some simple laboratory methods like lime: soil incubation, calcium hydroxide incubation and even soil pH measurement when calibrated with field experiments can be very useful in lime estimation. Soil pH measurement cannot be applied for lime estimation across soil types. Buffer methods of lime estimation can be useful in preparing quick lime estimation kits for only certain well defined soil types and not across different soils. These methods are not applicable in the very low buffered ferralsols of Busia and Kakamega counties. Only field trials can come up with lime requirements in these soils. The author recommends soil pH measurement with use of regression equations for lime estimation in acid soils of the eastern highlands and modified Mehlich buffer for development of a Quick lime estimation kit. The author further recommends further field liming trials in specific acid soil types for any application of the methods studied here in soils other than nitisols of eastern Kenya highlands.

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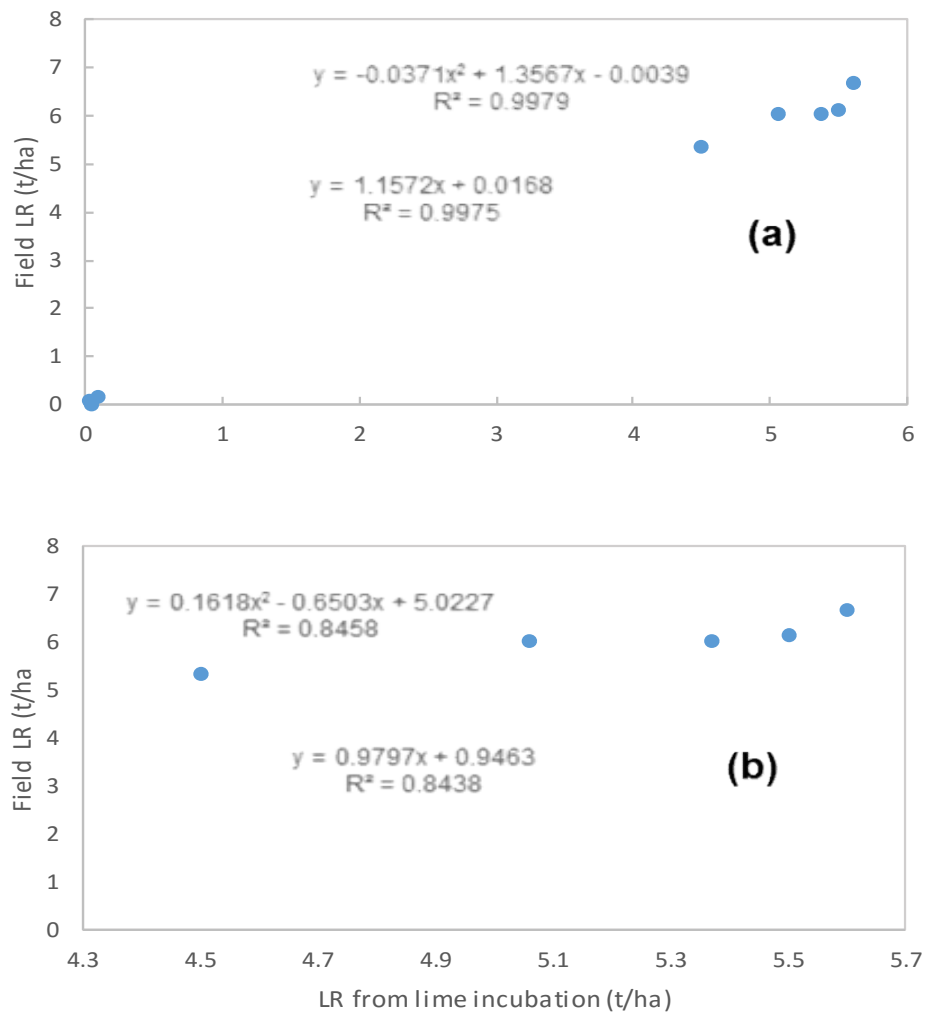
Figure 4

$y = -0.0371x^2 + 1.3567x - 0.0039$
$R^2 = 0.9979$

$y = 1.1572x + 0.0168$
$R^2 = 0.9975$

(a)

$y = 0.1618x^2 - 0.6503x + 5.0227$
$R^2 = 0.8458$

$y = 0.9797x + 0.9463$
$R^2 = 0.8438$

(b)

Fig. 4. **Relationship between LR from lime incubation and field LR in (a)Nitisols and ferralsols and (b) Nitisols**

==Table 2:== *Cofficients of determination (r2) for linear and curvilinear functions between field lime requirement (LR) to target pH 5.5 and both calculated lime requirements (LR) or soil: buffer pH with respective*

Buffer method	R² to target pH 5.5												Conversion factor(in the order; nitisols and ferallsols, nitisols and ferallsols)	% change from field LR (in the order; nitisols and ferallsols, nitisols and ferallsols)
	Soil:buffer pH and field LR						Calculated LR and field LR							
	Nitisols and ferralsols		Nitisols		Ferralsols		Nitisols and ferralsols		Nitisols		Ferralsols			
	Linear	Curvilinear	linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear	Linear	Curvilinear		
SMP single buffer	0.94	0.90	0.011	0.23	0.83	1.0	0.94	0.98	0.0016	0.37	0.998	1.0	0.59, 0.87,0.112	325,15,841
Mehlic single buffer	0.94	0.95	0.013	0.41	0.88	1.0	0.94	0.97	0.074	0.54	0.44	0.44	0.32, 0.49, 0.046	408,35,1030
Modified mehlic buffer	0.86	0.86	0.31	0.44	0.998	1.0	0.98	0.99	0.64	0.66	0.73	1.0	0.34, 0.46, 0.133	68,51,95
Adams and Evans	0.75	0.87	0.23	0.86	0.15	1.0	0.92	0.97	0.23	0.37	0.99	1.0	0.88,1.25, 0.26	-98,17,-291
SMP double buffer	-	-	-	-	-	-	0.88	0.98	0.33	0.81	0.52	1.0	0.45, 0.69, 0.0295	51,48,56
Yuan double buffer	-	-	-	-	-	-	0.97	0.997	o.74	0.79	0.68	1.0	0.87,1.25,0.26	28,20,-43