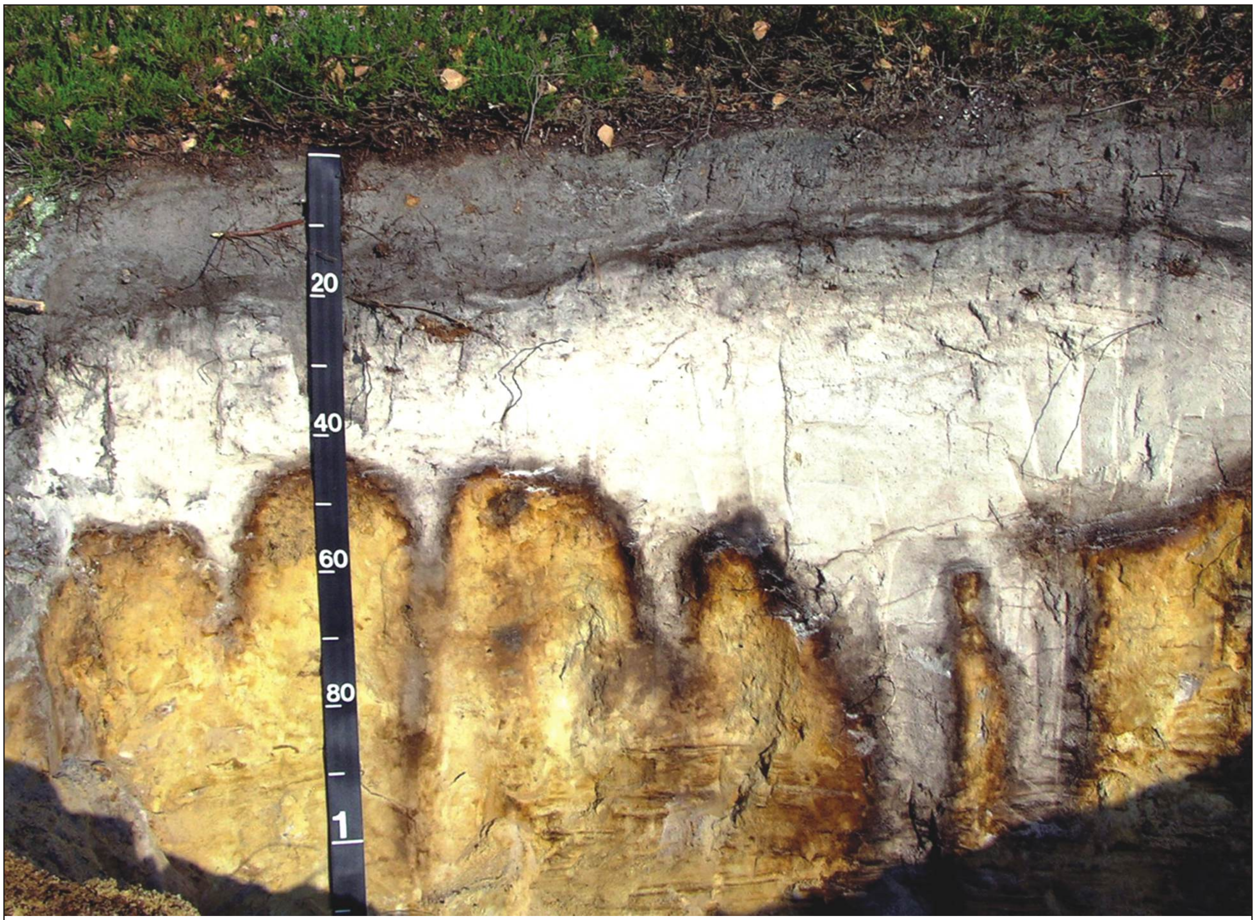

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Research Article

Assessment of Soil Properties and the Development of Lime Requirement Equations for Some Soils in South-Eastern Nigeria

[1]O.B. Iren, [2]D.J. Udoh, [1]V.F. Ediene and [1]E.E. Aki

[1]Department of Soil Science, University of Calabar, Calabar, Cross River State, Nigeria
[2]Department of Soil Science, Akwa Ibom State University, Obio Akpa Campus, AKS, Nigeria

Abstract

Background and Objective: Most of the soils of South-eastern Nigeria are strongly acidic. Liming these soils for profitable crop production requires the assessment of the soil properties and then developing model equations for calculating liming rates. This study aimed to assess the soil properties and then develop model equations and curves for quick calculations of liming rates. **Materials and Methods:** Soil samples were collected at 40 different locations in Cross River and Akwa Ibom States and analyzed. An incubation study was also performed to monitor changes in pH bi-weekly in the laboratory. Neutralization curves were constructed by plotting a maximum rise in pH against lime rates. **Results:** The soils were separated into particle-size classes, A (sandy clay loam and clay soils) and B (sandy loam and loamy sand soils). Soil properties were higher for group A than B. Multiple regression equations created provided several equations for calculating Lime Requirements (LR). The equations were: Group-A: LR = 0.33+0.28ΔpHxOM+0.18ΔpHxclay [R^2 = 0.855]. Group-B: LR = 0.98+0.58Δ pHxOM [R^2 = 0.552]. **Conclusion:** Over-liming can generate alkaline conditions that may create solubility problems. Therefore, both the regression equations and the curves are useful tools for quick determinations of lime requirement.

Key words: Buffering capacity, incubation, lime requirement, multiple regression, soil pH, soil properties

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Corresponding Author: O.B. Iren, Department of Soil Science, University of Calabar, Calabar, Cross River State, Nigeria

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

A major cause of poor crop yields in southeastern Nigeria is the low fertility status of the soils owing to a predominance of coastal and beach-ridge sand parent materials and a heavy rainfall regime. The soils developed are highly leached and therefore strongly acidic. Exposure of the land to prolonged rainfall after clearing and cropping also results in a denuding of the land of its fairly nutrient rich organic mantle[1]. Even with large applications of fertilizers, the fertility status of these soils remains fragile and transient, especially in the case of the acid sand soils that abound in the zone[2].

Most of these soils fall within the Acrisol, Alisol, Ferralsol and Lixisol reference soil groups (RSGs) of the World Resource Base (WRB) for soil classification. These soils are known to be low in pH, Base Saturation (BS), Cation Exchange Capacity (CEC), Organic Matter Content (O.M.) and also generally poor in nutrient assay[3-5].

One method of upgrading the fertility status of acidic and coarse textured soils in the hot, humid tropics is the technology of combining applications of fertilizer or manure with liming[1,6,7]. When the rate of organic matter decomposition is very high and the clay content low, there is bound to be serious handicaps in the sustenance of fertility[8]. Except organic matter content is quite high the role of clay, especially silicate clays is very important in the sustenance of fertility. Using agricultural lime to neutralize excess acidity and eliminate toxic levels of Al, Mn and Fe are obviously the cheapest and most effective way of improving the weak fertility status of acid sand soils[1,2]. The choice of liming is not just to raise soil pH, but also to enhance other soil conditions for higher levels of microbial activity, cation exchange reactions and nutrient availability. Liming will lower the solubility products of the acidic cations, Al, Fe and Mn, while raising the solubility products of P, K and Mg in mineral soils[9].

Every class and type of soil have its specific lime requirement-defined simply as the amount of lime (in $CaCO_3$ equivalents) needed to neutralize acid cations (mainly H^+ and Al^{3+}) while raising soil pH to target levels[10,11]. In the laboratory, such neutralization may be tested with buffer solutions such as proposed by Shoemaker *et al.*[12].

The technology of lime use includes the ability to identify when and how much of lime to apply (Lime requirement). It also requires knowledge in the selection of appropriate materials for each liming situation. Soils that are high in clay and Organic Matter (OM) exhibit higher buffering capacities and require more lime than sandy and low OM soils.

The objectives of this study were therefore to determine the physico-chemical properties of soils in the study area (Cross River and Akwa Ibom States) and to develop equations for calculating lime requirements based on key soil property values, for both individual soils and groups of similar soils.

MATERIALS AND METHODS

Environment and climate of the study area

Zone 1: The inland rain forest zone (this covers the central and northern parts of Cross River State) located between latitudes 4°2' and 5°32'N and longitudes 7°15' and 9°28'E. The climate is hot and humid with an annual rainfall range of 2,000-3000 mm, temperature range of 23-33°C and Relative Humidity (RH) of 65-90%. The soils developed mostly from basement rock complex and volcanic ash, also from alluvial sediments.

Zone 2: The coastal rain forest zone (this covers the Southern Cross River and Akwa Ibom States) located between latitudes 4°31' and 5° 20'N and longitudes 7°30' and 8°20' E. The climate is wet and humid with R.H. of 75-80%, annual rainfall of 2,500-3,500 mm, the temperature range of 23-29°C. The soils developed mostly from alluvial parent material - coastal plain and beach-ridge sands with influence, in some areas, from materials weathered from sandstone/shale and other sedimentary materials.

Duration of the study: This research project was conducted from April, 2018 to May, 2019.

Collection of soil samples: Twenty different locations in each of the two physiographic zones were identified and used for the study. Four composite soil samples were collected per site in each of the 20 locations within a zone to an auger depth of 20 cm. This gives a total of 80 soil samples per zone, meaning 160 soil samples for the two physiographic zones. The sampling sites were secondary bush or old farm in fallows of 2-4 years. The samples were placed in black polythene bags, labeled and taken to the University of Uyo Laboratory for analysis.

Laboratory studies

Determination of physico-chemical properties: The soil samples collected were air-dried and sieved with a 2 mm mesh sieve and stored in plastic bags with proper labelling. Particle size distribution was determined by the Bouyoucos hydrometer method, soil pH was read with a glass electrode pH-meter, SMP-pH was measured by the procedure of Shoemaker *et al.*[12] as described by Jones[13], with the buffer pH set at 7.5. Organic Carbon (OC) was determined by the

Walkley-Black wet oxidation method[14] and Organic Matter (OM) calculated with the 1.724 factor. Total nitrogen (N) was determined by using the modified macro-Kjeldahl method of Bremner[15]. Available P was extracted by the method of Bray and Kurtz[16] and P determined in the extract by the procedure of Murphy and Riley[17]. Calcium, Mg and K were extracted with 1 M NH_4OAc and Ca and Mg determined by EDTA titration. Potassium was determined by flame photometry. Effective Cation Exchange Capacity (ECEC) was determined by the summation of total exchangeable bases and total exchangeable acidity. Base saturation was calculated by dividing the sum of exchangeable bases by ECEC and then multiplied by 100.

Determination of lime requirement (incubation study): Following an appraisal of the mean values per site for the 40 locations, the test results obtained showed differences or similarities among textural class groups. It was considered appropriate to separate the soils into 2 groups designated 'A' for clay and sandy clay loam soils and 'B' for loamy sand and sandy loam soils. It was noted that the grouping was also largely related to the two main parent materials that underlie the soils of the study area. Basement complex and volcanic ash materials for the clay and sandy clay loam soils while coastal plain sand, alluvial and shale/sandstone materials were for sandy loam and loamy sand soils.

Fifty grams of air-dried soil samples from the A and B groups were weighed in 3 replicates into large, labeled, plastic cups and mixed thoroughly with $CaCO_3$ (<60-mesh) at the aliquot incremental rates of 0, 2, 4, 6, 8, 10 and 12 t ha^{-1}. The soils were wetted to field capacity with distilled water and the cups perforated at the bottom to allow outflow of excess water. They were then placed on greenhouse benches and allowed to incubate for 8 weeks. Initially at weekly intervals and later at fortnightly intervals, 5 g portions of soil from each cup were removed, air-dried and tested for both water pH and SMP-pH[13]. The data on pH values were carefully recorded. The periodic monitoring of pH change for each lime rate was continued with until changes in pH stopped for each set of cups. The maximum increase in pH under each level of lime treatment was thus monitored over an 8-week period.

Construction of neutralization curves: The mean maximum rise in pH under each of the six lime rates, plus control, for both the A and B groups of soils were plotted against the lime rate. Graphs were plotted for typical examples of soils from each of the particle size groups (sandy clay loam and clay group and loamy sand and sandy loam group) as shown in Fig. 1a, b. Similar graphs were plotted for each soil group as a whole (Fig. 2a, b). The plotted curves enabled the estimation of lime requirements for any desired level of pH under each soil group[18].

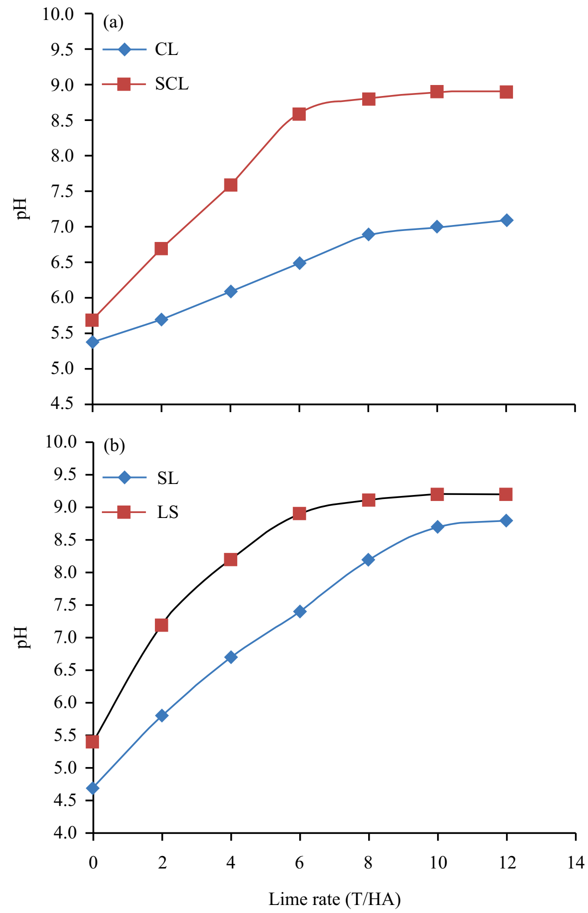

Fig.1(a-b): Neutralization curves for (a) CL, SCL and (b) SL and LS soils

CL: Clay, SCL: Sandy clay loam, SL: Sandy loam, LS: Loamy sand

Formulation of lime requirement equations: Soil test data, including water pH and SMP-pH, organic matter and clay contents obtained in the analysis of the samples were used for the construction of multiple regression models for predicting lime requirements.

Statistical analysis: Data on soil test and lime incubation studies were analyzed by descriptive statistics. The Pearson Product correlation analysis was used in assessing the relationship among soil properties. The means of significant parameters were compared using the Duncan Multiple Range Test.

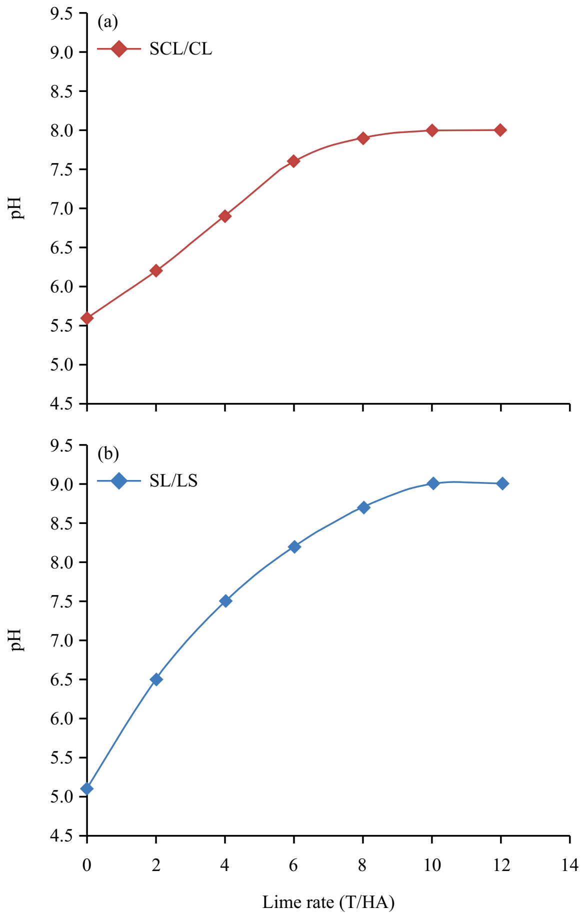

Fig. 2(a, b): Neutralization curves for (a) Group A and (b) B soils
CL: Clay, SCL: Sandy clay loam, SL: Sandy loam, LS: Loamy sand

RESULTS

Soil properties: Table 1 presents the properties of Group A soils (sandy clay loam and clay soils) and the quantity of lime required either by incubation or calculation to attain a pH level of 6.0 or 6.5. The properties tested were those frequently required in the course of soil study and fertility management. Soil pH in H_2O and in $CaCl_2$ values fall within very strongly acid to the slightly acid range with values ranging from 4.7-6.2 and 4.1-5.9, respectively while SMP-pH values fall within moderately acid to a neutral range (5.6-7.1). The mean soil pH (H_2O) was 5.6, 5.3 for pH in $CaCl_2$ and 6.3 for SMP-pH with corresponding Standard Deviations (SD) of 0.4, 0.5 and 0.3. Standard deviation serves as an estimate of variability. Soil Organic Matter (OM) and Total Nitrogen (TN) levels were very low to medium. The values ranged from 1.0-5.7% with a mean of 4.2% and 0.05-0.29% with a mean of 0.20% for OM and TN, respectively. Organic matter had standard deviation value of 1.1 while TN had 0.06 deviation. Available phosphorus

Table 1: Properties of group a soils (sandy clay loam and clay soils) and lime requirement by incubation and calculation

Soil sample location	Soil pH (H_2O)	Soil pH (0.01 MCacl$_2$)	Soil SMP-pH	OM (%)	T/N (%)	P (mg kg^{-1})	K	Ca	Mg	Clay (%)	Silt (%)	Sand (%)	Textural class	LR (Incub.) pH 6.0	LR (Incub.) pH 6.5	LR (Cal.) pH 6.0	LR (Cal.) pH 6.5
							----------cmol kg^{-1}----------										
Plantation Farm, Obudu-CRS	5.3	5.1	6.4	4.8	0.18	13	0.48	5.52	1.58	22	20	58	Scll	4.11	6.21	3.11	6.36
Mbube, Ogoja "	6.2	5.8	6.4	4.2	0.21	18	0.52	5.60	1.50	24	17	56	Scll	-	4.25	-	4.37
Cacao farm area, Ikom "	5.4	5.2	6.2	4.5	0.23	09	0.39	6.50	1.70	58	26	16	Cl	5.34	6.88	2.98	7.30
Ikom tree crop nursery "	5.8	5.8	6.2	4.6	0.23	14	0.36	5.90	0.48	62	27	11	Cl	1.25	7.02	2.51	8.53
By TTC, Ikom, "	5.2	4.9	5.6	5.2	0.26	20	0.19	3.05	1.39	61	26	13	Cl	8.78	17.05	8.03	15.30
Govt. Farm, Ogoda "	5.7	5.7	6.5	3.3	0.17	08	0.41	6.33	2.64	27	21	52	Scll	1.25	4.01	1.76	4.77
Ekori, Obubra "	6.0	5.9	7.1	1.0	0.05	12	0.32	3.65	0.80	25	20	55	Scll	-	1.00	-	0.50
Agric. Station, Obubra "	5.9	5.4	6.0	5.7	0.29	20	0.38	8.24	4.16	48	43	20	Cl	0.75	10.78	2.01	8.78
Obubra fallow farm "	5.4	5.3	6.4	3.8	0.19	11	0.50	4.70	3.50	49	26	25	Cl	3.25	6.11	2.78	6.13
SMC Iyamoyong "	5.5	5.5	6.1	4.3	0.21	05	0.54	6.20	2.14	50	27	23	Cl	4.26	8.78	4.26	9.53
Oku Iboku, Itu- AKS	5.7	5.5	6.3	3.5	0.18	142	0.12	0.50	0.26	23	03	74	scll	5.52	5.52	2.01	5.77
Farm area, Ik. Ekpene "	4.7	4.6	6.5	4.9	0.25	151	0.13	0.38	0.20	21	07	72	scll	6.02	6.02	4.77	6.77
Ini/Ikono cocoa area "	5.3	4.8	6.1	3.9	0.19	21	0.46	4.32	2.22	26	20	54	scll	2.43	5.25	3.84	6.44
3 yearr bush fallow, Oron" "	5.6	4.1	6.3	3.5	0.09	038	0.14	6.80	3.80	24	06	70	scll	2.21	5.42	2.22	6.28
CRBDA land, Okobo "	6.2	5.3	6.6	5.4	0.27	18	0.15	9.00	2.80	23	05	72	scll	-	4.11	-	3.22
Mean values	5.6	5.3	6.3	4.2	0.20	33.3	0.34	5.11	1.94	36.2	19.6	44.7		3.48	6.56	3.10	6.67
Std. Dev. (+)	0.4	0.5	0.3	1.1	0.06	46.6	0.15	2.45	1.26	16.1	10.8	23.9		2.51	3.65	1.91	3.29
Range	4.7-6.2	4.1-5.9	5.6-7.1	1.0-5.7	0.05-0.29	5-151	0.12-0.54	0.38-9.00	0.20-4.16	21-62	3-43	11-74					

OM: Organic matter, TN: Total nitrogen, LR: Lime requirement, cl: Clay, scll: Sandy clay loam, SMP-pH: Shoemaker, McLean and Pratt-pH, CRS: Cross river state, AKS: Akwa Ibom State, ": Indicating that the location is in the same state as the previously mentioned contents in all the Group A studied soils were high except in SMC Iyamoyong location which was low (5 mg kg^{-1}) and the values ranged from 5-151 mg kg^{-1} with a mean of 33.3 mg kg^{-1} and standard deviation value of 46.6 (Table1). Exchangeable potassium (K) contents varied from very low to moderate, 0.12-0.54 with a mean value of 0.34 cmol kg^{-1} and SD value of 0.15. Exchangeable calcium (Ca) contents ranged from 0.38-9.00 cmol kg^{-1} with a mean of 5.11 cmol kg^{-1} and SD of 2.45 while exchangeable magnesium (Mg) values ranged from 0.20-4.16 cmol kg^{-1} with mean of 1.94 cmol kg^{-1} and SD value of 1.26. The results of the particle size distribution indicate that the soils had sandy clay loam to clay texture with individual components of clay, silt and sand ranging from 21-62% (mean, 36.2%), 3-43%, (mean, 19.6%) and 11-74 % (mean, 44.7%), respectively. Their corresponding standard deviation values were 16.1, 10.8 and 23.9.

All Lime Requirement (LR) values obtained through both calculation and incubation were recorded (Table 1). Based on the soil pH (H_2O) values determined (Table 1), Plantation Farm, Obudu with soil pH value of 5.3 required 4.11 t ha^{-1} of lime to raise the soil pH from the initial level (5.3) to a target pH of 6.0 and 6.21 t ha^{-1} of lime was required to raise the soil pH to a target pH of 6.5 by incubation method whereas by calculation method, the L.R. was 3.11 t ha^{-1} for 6.0 target and 6.36 t ha^{-1} for 6.5 target pH. At Mbube, Ogoja location, where the soil pH value was 6.2, no lime was required at the 6.0 target pH level but for a target pH of 6.5, 4.25 t ha^{-1} of lime was required. The same was done and recorded for all the 15 soil sample locations of Group A. Mean L.R. (incubation) for a target pH of 6.0 was 3.48 t ha^{-1} of lime with SD of 2.51 and for 6.5 target the mean L.R. was 6.56 t ha^{-1} with SD of 3.65. Mean L.R. by calculation for pH 6.0 was 3.10 t ha^{-1} with SD of 1.91 while for a target pH of 6.5, LR mean value was 6.67 t ha^{-1} with SD value of 3.29. (Table 1). Generally, the lime requirement (L.R.) results obtained by incubation were slightly higher than the values obtained by calculation but in some locations, the reverse was the case.

Table 2 shows the correlation matrix of the soil properties for Group A soils. The correlation between soil pH (H_2O) and soil pH ($CaCl_2$) was positive and significant (r = 0.889*), also with exchangeable Ca (r = 0.392*) but was not significant with SMP pH (r = 0.457), exchangeable K (r = 0.365), Mg (r = 0.223) and silt contents (r = 0.228) though they were positively correlated meaning that an increase in soil pH (H_2O) will increase these soil properties. Soil pH (H_2O) was negatively correlated but not significant with soil organic matter (r = -0.618), total nitrogen (r = -0.582), phosphorus (r = -.498), clay (r = -0.069) and sand contents (r = -0.143) indicating that an increase in soil pH leads to reduction of these soil properties. Soil pH ($CaCl_2$) was positively correlated though not significant with SMP pH (r = 0.503), K (r = 0.124), Ca (r = 0.335), Mg (r = 0.102) and silt contents (r = 0.320) while with organic matter (r = -0.642), total nitrogen (r = -0.584), phosphorus (r = -0.456), clay (r = -0.097) and sand contents (r = -0.219), it was negative and also not significant. The correlation matrix also shows a highly significant but negative correlation between SMP pH and organic matter (r = -0.720**), also with total nitrogen (r = -0.725*) and clay (r = -0.508*) while with sand, it was positive and significant (r = 0.220*) and positive but not significant with calcium (r = 0.125). However, SMP pH also had negative but not significant correlations with P (r = -0.519), K (r = -0.109), Mg (r = -0.043) and silt (r = -0.007). The correlation between organic matter (OM) and total nitrogen was positive and highly significant (r = 0.984**). This indicates that the availability of OM will increase total nitrogen contents in the soil. Organic matter also had positive but not significant relationship with phosphorus (r = 0.688) and even clay (r = 0.360) while with K (r = -0.224), Ca (r = -0.387), Mg (r = -0.240), silt (r = 0.068) and sand (r = -0.101) the relationship was negative and not significant (Table 2). Total nitrogen had positive but not significant relationship with P (r = 0.736) and clay (r = 0.397) while with K (r = -0.225), Ca (r = -0.429), Mg (r = -0.294), silt (r = -0.059) and sand (r = -.129), the correlation was negative and not significant.

Table 2: Correlation matrix for group a soils (sandy clay loam and clay soils)

	Soil pH	Soil pH	Soil				K	Ca	Mg			
Soil properties	(H_2O)	$CaCl_2$	SMP-pH	O.M. (%)	TN (%)	P (mg kg^{-1})	-------------cmol kg^{-1}-------------			Clay (%)	Silt (%)	Sand (%)
Soil pH (H_2O)	1	0.889*	0.457	-0.618	-0.582	-0.498	0.365	0.392*	0.223	-0.069	0.228	-0.143
pH.$CaCl_2$	-	1	0.503	-0.642	-0.585	-0.456	0.124	0.335	0.102	-0.097	0.320	-0.219
SMP-pH	-	-	1	-0.720**	-0.725*	-0.519	-0.109	0.125	-0.043	-0.508*	-0.007	0.220*
OM	-	-	-	1	.984**	0.688	-0.224	-0.387	-0.240	0.360	-0.068	-0.101
T/N	-	-	-	-	1	0.736	-0.225	-0.429	-0.294	0.397	-0.059	-0.129
P	-	-	-	-	-	1	-0.180*	-0.524**	-0.424	0.590	0.104*	-0.350
K	-	-	-	-	-	-	1	0.272	0.292	0.329	-0.029	-0.084
Ca	-	-	-	-	-	-	-	1	0.839	-0.264	-0.116	0.221
Mg	-	-	-	-	-	-	-	-	1	-0.184	-0.102	0.184
Clay	-	-	-	-	-	-	-	-	-	1	0.309	-0.671
Silt	-	-	-	-	-	-	-	-	-	-	1	-0.911
Sand	-	-	-	-	-	-	-	-	-	-	-	1

OM: Organic matter, T/N: Total nitrogen, **Significant at the 1% level, *Significant at the 5% level

The correlation between phosphorus and Ca was negative and highly significant (r = -0.524**) meaning that the availability of soil available phosphorus will increase with decreasing values of Ca. Significant but negative correlation also existed between available phosphorus and K (r = -0.180*), that with silt was positive and significant (r = 0.104*) while that with Mg (r = -0.424), clay (r = 0.590) and sand (r = -0.350) were not significant. Exchangeable K though not significant was positively correlated with Ca (r = 0.272), Mg (r = 0.292) and clay (r = 0.329) while with silt (r = -0.029) and sand (r = -0.084), it was negative. Exchangeable Ca was not significantly correlated with Mg (r = .839), clay (r = -0.264), silt (r = -0.116) and sand (r = 0.221) likewise exchangeable Mg was not significantly correlated with clay (r = -.184), silt (r = -0.102) and sand (r = 0.184)

The soil properties for Group B soils (sandy loam and loamy sand) and the quantity of lime required either by incubation or calculation to attain a pH level of 6.0 or 6.5 are as given in Table 3. Soil pH in H_2O values fall within very strongly acid to the slightly acid range with values ranging from 4.5-6.5, pH in $CaCl_2$ values fall within extremely acid to moderately acid (3.8-5.6), while SMP-pH values fall within moderately acid to neutral range (6.0-7.1). The mean soil pH (H_2O) was 5.3, 4.7 for pH in $CaCl_2$ and 6.6 for SMP-pH with corresponding Standard Deviations (SD) of 0.5, 0.6 and 0.3. Soil Organic Matter (OM) and Total Nitrogen (TN) levels were very low to medium. The values ranged from 1.3-6.0% with a mean of 3.5 and 0.04-0.30% with a mean of 0.18% for OM and TN, respectively with corresponding standard deviation values of 1.6 and 0.08. Available phosphorus contents in Group B soils were rated low to high and the values ranged from 4-238 mg kg^{-1} with a mean of 59.9 mg kg^{-1} and a standard deviation value of 68.6 (Table 3). Exchangeable potassium (K) contents ranged from 0.07-0.69 cmol kg^{-1} with a mean value of 0.22 cmol kg^{-1} and SD value of 0.13. Exchangeable calcium (Ca) contents ranged from 0.2-4.80 cmol kg^{-1}, with mean of 2.10 cmol kg^{-1} and SD of 1.38 while exchangeable magnesium (Mg) values ranged from 0.14-2.40 cmol kg^{-1} with mean of 0.93 cmol kg^{-1} and SD value of 0.70. The results of the particle size distribution indicate that the soils had sandy loam to loamy sand texture with each component of clay, silt and sand fraction ranging from 6.0-19% (mean, 13.8%), 2-24%, (mean, 7.3%) and 59-89% (mean, 79%), respectively. Their respective standard deviation values were 3.4, 6.0 and 7.8.

Similarly, all Lime Requirement (LR) values obtained through both calculation and incubation were recorded for all the 25 soil sample locations of Group B soils (Table 3). Mean L.R. (incubation) for a target pH of 6.0 was 2.96 t ha^{-1} of lime with SD of 1.92 and for 6.5 target the mean L.R. was 3.95 t ha^{-1} with SD of 2.05. Mean L.R. by calculation for pH 6.0 was 2.29 t ha^{-1} with SD of 1.50 while for a target pH of 6.5, L.R. mean value was 4.05 t ha^{-1} with SD value of 2.16. (Table 3).

Table 4 shows the correlation matrix of the soil properties for Group B soils. The correlation between soil pH (H_2O) and soil pH ($CaCl_2$) for Group B soils was also positive and highly significant (r = 0.615**) also with SMP pH (r = 0.335**) while with soil organic matter (r = -0.203**), total nitrogen (r = -0.136**) and phosphorus (r = -0.400*) the correlation was negative but also significant. However, soil pH (H_2O) and soil pH ($CaCl_2$) had no significant correlation with the exchangeable bases (K, Ca, Mg) and the soil separates (clay, silt, sand). Soil pH ($CaCl_2$) was positively correlated with SMP pH (r = 0.317**) and total nitrogen (r = 0.009**) but negatively with organic matter (r = -0.267**) and phosphorus (r = -0.294**). There was also a highly significant but negative correlation between SMP pH and organic matter (r = -0.648**) and even with total nitrogen (r = -0.582**) and clay (r = -0.613*) while with P, it was positive and significant (r = 0.078*) but not significant with exchangeable bases, silt and clay fractions. The correlation between Organic Matter (OM) and total nitrogen for Group B soils was also positive and highly significant (r = 0.911**) and even with phosphorus (r = 0.034**). This indicates that the availability of OM will increase total nitrogen and phosphorus contents in the soil. However, organic matter was not significantly correlated with the exchangeable bases and the soil separates. Total nitrogen had positive and highly significant relationship with P (r = 0.074**) and also with calcium (r = 0.167*) and even with clay (r = 0.423*) while with K (r = -0.012), Mg (r = 0.048), silt (r = 0.305) and sand (r = -.379), the correlation was not significant. The correlation between phosphorus and K was negative and not significant (r = -0.640) but with Ca (r = -0.750**), Mg (r = -0.491*) and clay (r = -0.399**) the relationships though negative were significant while that with silt and sand were not significant. Though exchangeable K was not significantly correlated with Ca, Mg and the soil separates, exchangeable Ca had a highly significant and positive correlation with Mg (r = 0.708**) but not with the soil separates. A highly significant but negative correlation existed between clay and sand contents (r = -0.965**) and likewise between silt and sand contents (r = -0.856**) meaning the higher the clay and silt particles in the soil the lower the sand contents.

A summary of soil properties for "all soils" combined and groups A and B soils is given in Table 5. For "all soils" the mean pH is 5.4$\pm$0.2 and the range 4.5-6.5, group A soils show mean pH as 5.6$\pm$0.4 and range 4.7-6.2 and for group B soils, mean pH is 5.3$\pm$0.5 and range 4.5-6.5. Similarly, mean content of

Table 3: Soil Properties of Group B soils (sandy loam & loamy sand), lime requirement by incubation and by calculation

Soil sample location		Soil pH (H_2O)	Soil pH (0.01 MCacl$_2$)	Soil SMP-pH	OM (%)	T/N (%)	P (mg kg^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	Clay (%)	Silt (%)	Sand (%)	Textural class	LR (Incub.) pH 6.0	LR (Incub.) pH 6.5	LR (Cal.) pH 6.0	LR (Cal.) pH6.5
N/Farm, Obudu –	CRS	6.0	5.6	6.7	2.2	0.11	004	0.32	3.00	1.62	15	21	64	sl	-	2.51	-	2.51
Ukprinyi, Obudu	"	5.9	5.5	6.9	1.8	0.09	005	0.13	2.68	1.03	14	24	62	sl	0.50	1.76	0.25	1.25
Ogboja, Ogoja	"	5.9	5.5	7.0	1.3	0.07	019	0.14	1.74	0.97	11	08	81	sl	0.50	1.25	0.25	0.75
Ukpe, Ogoja	"	6.5	5.6	7.1	1.5	0.08	009	0.25	2.30	0.68	08	07	85	ls	-	-	-	0.00
Okuni, Ikom	"	5.4	4.8	6.8	2.1	0.15	150	0.42	1.87	0.58	18	05	77	sl	1.25	2.01	1.76	3.01
Edor Ogoja-Ikom Rd.	"	5.1	4.9	6.6	1.8	0.09	008	0.38	1.48	0.55	14	06	80	sl	2.51	3.51	2.26	4.01
Ugep	"	5.0	4.2	7.1	1.4	0.04	010	0.20	1.13	0.25	10	03	87	ls	1.25	2.26	1.25	2.26
Orira, Akamkpa	"	6.1	5.3	6.6	3.2	0.16	065	0.30	3.85	1.01	17	06	77	sl	-	1.25	-	3.01
Mbarakom, Akamkpa	"	5.7	5.0	6.8	2.4	0.12	014	0.21	1.48	0.46	14	06	80	sl	2.26	2.26	1.00	2.26
R/Estate, Akamkpa	"	5.4	4.7	6.5	3.3	0.17	007	0.22	1.13	0.59	16	07	77	sl	4.01	4.01	2.26	4.51
Okoyong., Odukpani	"	5.5	5.3	6.7	4.0	0.20	046	0.21	1.30	0.23	13	08	79	sl	4.40	5.10	3.20	7.30
Ik. Efanga, Calabar	"	4.7	3.9	6.3	5.2	0.28	054	0.12	0.21	0.14	10	03	87	ss	5.00	6.27	3.76	6.27
Mbak Itam, Itu	AKS	5.5	5.0	6.3	4.7	0.24	084	0.21	2.97	1.34	18	02	80	sl	5.16	5.77	2.51	5.77
Uruk usuk, Ik.Ekpene	"	4.5	3.8	6.5	4.8	0.24	150	0.07	0.27	1.14	15	03	82	sl	6.02	7.02	4.51	6.02
Ikot Ntuen Oku, Uyo	"	4.8	4.1	6.0	5.9	0.30	238	0.26	0.94	0.28	18	09	73	sl	7.53	8.53	5.27	8.03
Ikot Akan, Ik. Abasi	"	5.0	4.3	6.5	6.0	0.30	170	0.12	0.63	0.32	19	09	72	sl	4.51	4.51	4.01	6.02
By Sec. School, Ibagwa	"	4.8	4.0	6.7	5.8	0.29	103	0.12	0.21	0.19	13	05	82	sl	3.76	5.77	3.76	4.26
Agric. Farm , Etinan	"	4.5	4.0	6.3	5.6	0.28	192	0.13	0.33	0.16	19	22	59	sl	4.51	6.02	3.51	8.03
Ediene Abak	"	5.0	4.7	6.7	5.5	0.28	076	0.13	1.90	0.35	11	04	85	ls	2.01	4.26	2.26	3.01
Mbak Etoi, Uyo	"	5.3	4.8	6.8	2.7	0.13	029	0.19	4.20	2.30	12	02	86	Ls	2.60	3.57	1.72	2.40
Idu, Uruan	"	5.2	4.5	6.6	3.2	0.16	009	0.25	3.60	1.40	12	03	85	Ls	3.23	4.67	2.26	3.70
Nsukara Offot, Uyo	"	5.2	4.6	6.4	2.8	0.14	009	0.21	3.50	1.45	14	05	81	Sl	3.33	5.32	2.64	4.97
AKSU Farm, OAC	"	5.7	4.2	6.3	4.4	0.20	015	0.69	3.20	2.30	17	07	78	Sl	3.11	5.00	3.92	5.18
Ik Eka Ide, Oruk Anam	"	5.0	4.4	6.5	3.6	0.17	019	0.08	4.80	2.40	06	05	89	ls	2.60	3.23	2.17	3.86
Minya, Mkpat Enin	"	4.7	4.0	6.3	3.4	0.14	013	0.25	3.80	1.43	12	03	86	ls	2.80	2.80	2.80	2.80
Mean		5.3	4.7	6.6	3.5	0.18	59.9	0.22	2.10	0.93	13.8	7.3	79		2.96	3.95	2.29	4.05
Std. Dev.		0.5	0.6	0.3	1.6	0.08	68.6	0.13	1.38	0.70	3.4	6.0	7.8		1.92	2.05	1.50	2.16
Range		4.5 - 6.5	3.8–5.6	6.0 -7.1	1.3- 6.0	0.04-0.3	4-238	0.07-0.69	0.21-4.8	0.14-2.4	6.0-19	2-24	59-89					

Sl: Sandy loam, Ls: Loamy Sand, OM: Organic matter and T/N: Total nitrogen, ": Indicating that the location is in the same state as the previously mentioned

Table 4: Correlation matrix for group B soils (sandy loam and loamy sand soils)

Soil properties	Soil pH (H_2O)	Soil pH $CaCl_2$	Soil SMP-pH	O.M. (%)	TN (%)	P (mg kg^{-1})	K	Ca	Mg	Clay (%)	Silt (%)	Sand (%)
							-------------cmol kg^{-1}	--------------				
Soil pH (H_2O)	1	0.615**	0.335**	-0.203**	-0.136**	-0.400*	0.110	0.556	0.226	-0.115	0.034	0.074
Soil pH (.01M$CaCl_2$)	-	1	0.317**	-0.267**	0.009**	-0.294*	0.437	0.125	-0.258	0.167	0.338	-0.266
Soil SMP.pH	-	-	1	-0.648**	-0.582**	0.078*	-0.043	-0.038	-0.172	-0.613*	-0.410	0.565
OM (%)	-	-	-	1	0.911**	0.034**	-0.058	0.285	0.196	0.334	0.216	-0.279
T/N (%)	-	-	-	-	1	0.074**	-0.012	0.167*	0.048	0.423*	0.305	-0.379
P (mg kg^{-1})	-	-	-	-	-	1	-0.640	-0.750**	-0.491*	-0.399**	-0.597	0.532
K (cmol kg^{-1})	-	-	-	-	-	-	1	0.334	0.219	0.241	0.623	-0.445
Ca (cmol kg^{-1})	-	-	-	-	-	-	-	1	0.708**	0.196	0.369	-0.259
Mg(cmol kg^{-1})	-	-	-	-	-	-	-	-	1	0.074	0.323	-0.134
Clay (%)	-	-	-	-	-	-	-	-	-	1	0.709	-0.965**
Silt (%)	-	-	-	-	-	-	-	-	-	-	1	-0.856**
Sand (%)	-	-	-	-	-	-	-	-	-	-	-	1

O.M.: Organic matter, T/N: Total nitrogen, **Significant at the 1% level, *Significant at the 5% level

Table 5: A summary of the soil properties of the study areas

Soil properties	All Soils		Group A soils (Predominant in cross river state)		Group B soils (Predominant in Akwa Ibom and Southern CR states)	
	Mean value	Range	Mean value	Range	Mean value	Range
Soil pH: (1:1, H_2O)	5.40±0.2	4.5-6.5	5.60+0.4	4.7-6.2	5.30±0.5	4.5-6.5
: (0.01M $CaCl_2$)	4.90±0.2	3.8-5.9	5.30±0.5	4.1-5.9	4.70±0.6	3.8-5.6
: (SMP-pH)	6.50±0.1	5.6-7.1	6.30±0.3	5.6-7.1	6.60±0.3	6.0-7.1
Soil O.M. (%)	3.80±0.4	1.0-0 6.0	4.20±1.1	1.0-5.7	3.50±1.6	1.3-6.0
Total N (%)	0.19±0.02	0.04-0.30	0.20±0.06	0.05-0.29	0.18±0.08	0.04-0.3
Available P (mg kg^{-1})	0.50±19	4-238	33.30±46.6	5-151	59.90±68.6	4-238
Exch. K (cmol kg^{-1})	0.27±0.05	0.07-0.69	0.34±0.15	0.12-0.54	0.22±0.13	0.1-0.7
Exch. Ca (cmol kg^{-1})	3.23±0.73	0.21-9.00	5.11±2.45	0.38-9.00	2.10±1.38	0.21-4.8
Exch. Mg (cmol kg^{-1})	1.31±0.33	0.14-4.16	1.94±1.26	0.20-4.16	0.93±0.70	0.14-2.4
Clay (%)	22.20±4.6	6-62	36.20±16.1	21-62	13.80±3.4	6.0-19.0
Silt (%)	11.90±3.1	2-43	19.60±10.8	3-43	7.30±6.0	2.0-24.0
Sand (%)	66.10±7.1	11-89	44.70±23.9	11-74	0.79±7.8	59.0-89.0
Textural class	-	ls, sl, scll	-	scll, cl	-	sl, ls
Lime Req.: (Incub) @pH 6.0:	-	-	3.50±2.5	-	2.90±1.9	-
" " " @pH 6.5	-	-	6.60±3.8	-	3.90±2.1	-
Lime Req.: (Calcu.) @pH 6.0:	-	-	3.10±1.9	-	2.30±1.5	-
" " " @pH 6.5	-	-	6.70±3.3	-	4.10±2.2	-

Incub: Incubated, Calc: Calculated, ls: Loamy sand, sl: Sandy loam, scll: Sandy clay loam, cl: clay and O.M: Organic matter

OM is 3.8±0.4% and range 1.0-6.0% for "all soils", 4.2±1.1% with range of 1.0-5.7% for group A soils and 3.5±1.60%, with range of 1.3-6.0% for group B soils. The soil organic matter content was generally low. Total N was low, ranging from 0.04-0.30%, with a mean of 0.19±0.02%. Available P was low for some samples and very high for others (04-238 mg kg^{-1}), with a mean of 50±19 mg kg^{-1}. Potassium ranged from 0.07-0.69 cmol kg^{-1}, with a mean of 0.27±0.05 cmol kg^{-1}, Ca, from 0.21-9.00 cmol kg^{-1}, with a mean of 3.23±0.73 cmol kg^{-1} and Mg from 0.14-4.16 cmol kg^{-1}, with a mean of 1.31±0.33 cmol kg^{-1}. The mean values of most soil properties are higher in A group than B group soils, except with respect to sandiness and availability of P. Mean value for L.R. (incubation) for Group A soils at a target pH of 6.0 was 3.5±2.5 t ha^{-1} of lime and for 6.5 target the mean L.R. was 6.6±3.8 t ha^{-1} whereas for Group B soils the L.R. was respectively 2.9±1.9 t ha^{-1} and 3.9±2.1 t ha^{-1}. Mean values for L.R. (calculation) for a target pH of 6.0 and 6.5 for Group A were 3.1±1.9 t ha^{-1} and 6.7±3.3 t ha^{-1}, while for Group B soils the values were and 2.3±1.5 t ha^{-1} and 4.1±2.2 t ha^{-1} of lime, respectively. The strong influence that parent materials, physiography and soil particle size class have on soil properties and fertility indicators are all revealed in Table 5.

Multiple regression equations models for determining lime requirements by calculation for Group A soils were developed as reported in Table 6. For the desired soil pH levels of 5.5, 6.0 and 6.5, lime requirement can be calculated by fitting the values of known soil parameters (pH, OM, Clay) into applicable L.R. equations developed. When only pH and clay were used as factors in calculating L.R. for target pH of 5.5 the equation developed was:

$$L.R. = 0.38 \pm 0.18\Delta pH \bullet cl$$

the coefficient of determination (R^2) was 0.712, then for target pH of 6.0 the equation was:

$$L.R. = 0.48 \pm 0.18\Delta pH \bullet cl \ (R^2 = 0.823)$$

while for target pH of 6.5 the equation was:

$$L.R. = 0.55 \pm 0.20\ \Delta pH \bullet cl \ (R^2 = 0.766)$$

all the R^2 values obtained were high and highly significant. However, when another factor, OM, was added to pH and clay in calculating L.R. for pH levels of 5.5, 6.0 and 6.5, the corresponding equations developed were:

$$L.R. = 0.28 \pm 0.23\ \Delta pH \bullet OM \pm 0.13\Delta pH \bullet cl$$

$$L.R. = 0.33 \pm 0.20\ \Delta pH \bullet OM \pm 0.15\Delta pH \bullet cl$$

$$L.R. = 1.63 \pm 0.15\ \Delta pH \bullet OM \pm 0.75\ \Delta pH \bullet cl$$

with highly significant R^2 of 0.735, 0.855 and 0.884 (Table 6). This indicates that the equations on Table 6 are more suitable for clayey soils when the clay factor is added to pH and OM. The influence of soil textural class is also quite significant as observable when the R^2 values of equations involving only the two soil factors (pH and clay) become very close to those involving the factors of pH, OM and clay. This emphasizes that clay plays a dominant role in the L.R. characteristic of soils.

Multiple regression equations were also developed for Group B soils as presented in Table 7. When only pH and OM were used as factors in calculating L.R. the following equations were developed:

$$L.R. = 0.60 \pm 0.55\Delta pH \bullet OM$$

$$L.R. = 0.98 \pm 0.58\ \Delta pH \bullet OM$$

$$L.R. = 2.45 \pm 0.55\Delta pH \bullet OM$$

for target pH of 5.5, 6.0 and 6.5 with respective R^2 values of 0.574, 0.552 and 0.260 indicating low but highly significant coefficient of determination. When soils are low in clay these equations become very useful, especially when organic matter is high. However, when pH, clay and SMP pH were used as soil factors, the values of R^2 increased significantly with values of 0.716, 0.832 and 0.895 recorded for target pH of 5.5, 6.0 and 6.5. Their corresponding regression equations were:

$$L.R. = 4.85 \pm 0.18\ \Delta pH \bullet cl\text{-}0.68SMPpH$$

$$L.R. = 7.35 \pm 0.15\ \Delta pH \bullet cl\text{-}1.03SMPpH$$

Table 6: Regression equations for calculating lime requirements for group a soils

Desired pH	Independent soil factors	Lime requirement equation⁺		Sig. Level	R^2
5.5	ΔpH, clay	L.R. = 0.38+0.18ΔpH•cl	(Suitable for clay soils)	**	0.712
6.0		L.R. = 0.48+0.18ΔpH•cl		**	0.823
6.5		L.R. = 0.55+0.20ΔpH•cl		**	0.766
5.5	O.M. ΔpH, clay	L.R. = 0.28+0.23ΔpH•OM+0.13ΔpH•cl	(Suitable for clayey soils)	**	0.735
6.0		L.R. = 0.33+0.20ΔpH•OM+0.15ΔpH•cl		**	0.855
6.5		L.R. = 1.63+0.15ΔpH•OM+0.75ΔpH*cl		**	0.884

pH: Change in pH, O.M.: Organic matter, R^2: Coefficient of determination, **: p<0.01

Table 7: Regression equations for calculating lime requirements for group b soils

Desired pH	Independent soil factors	Lime requirement equation⁺		Sig. Level	R^2
5.5	pH O.M.	L.R. = 0.60+0.55ΔpH•OM	Suitable for ls and sl soils	**	0.574
6.0		L.R. = 0.98+0.58ΔpH•OM		**	0.552
6.5		L.R. = 2.45+0.55ΔpH•OM		**	0.260
5.5	pH, clay SMP pH	L.R. = 4.85+0.18ΔpH•cl-0.68SMPpH	Suits sl, ls and slightly clayey soils	**	0.716
6.0		L.R. = 7.35+0.15ΔpH•cl-1.03SMPpH		**	0.832
6.5		L.R. = 40.98+0.1ΔpH•cl-5.95SMPpH		**	0.895

pH: Change in pH, O.M.: Organic matter, R^2: Coefficient of determination, **: p<0.01

Table 8: Regression equations with four properties that most affect lime requirement

Desired pH	Independent soil factors	Lime requirement equation⁺	Sig. Level	R^2
5.5	pH, clay, O.M. SMP pH	L.R. = 6.78+0.28ΔpH•OM+0.10ΔpH•cl-1.0SMPpH	**	0.712
6.0		L.R. = 8.58+0.23ΔpH•OM+0.13ΔpH•cl-1.23SMPpH	**	0.823
6.5		L.R. = 39.18+0.08ΔpH•OM+0.08ΔpH•cl-5.6SMPpH	**	0.766

SMP: Shoemaker, McLean and Pratt, pH: Change in pH, O.M.: Organic matter, R^2: Coefficient of determination, **:p<0.01

Table 9: Comparison of factors that affect lime requirement for the two groups of soils

	Group A soils (Higher clay content)				Group B soils (Lower clay content)			
	By incubation		By calculation		By incubation		By calculation	
	pH 6.0	pH 6.5	pH 6.0	pH 6.5	pH 6.0	pH 6.5	pH 6.0	pH 6.5
Lime Req. at two pH levels (t ha^{-1})	3.48	6.56	3.10	6.67	2.96	3.95	2.29	4.05
Other affecting soil properties								
Soil pH	5.6				5.3			
SMP-pH (differential)	1.2 (7.5-6.3 = 1.2)				0.9 (7.5-6.6 = 0.9)			
Soil O.M. (%)	4.2				3.5			
Clay content (%)	36.2				13.8			

SMP: Shoemaker, O.M.: Organic matter

$$L.R. = 40.98 \pm 0.1\ \Delta pH \bullet cl\text{-}5.95SMPpH$$

This indicates that the equations on Table 7 are suitable for sandy loam, loamy sand and slightly clayey soils. However, if all the four soil properties (soil pH, SMP-pH, soil O.M. and clay content) that mostly affect L.R. are available, then Table 8 presents the regression equations that can be used to achieve the desired pH level. For 5.5 desired pH, the equation developed was:

$$L.R. = 6.78 \pm 0.28\ \Delta pHOM \pm 0.10\Delta pH \bullet cl\text{-}1.0SMPpH$$

for 6.0 pH the equation was:

$$L.R. = 8.58 \pm 0.23\Delta pHOM \pm 0.13\Delta pH \bullet cl\text{-}1.23SMPpH$$

while for 6.5 pH the equation was:

$$L.R. = 39.18 \pm 0.08\Delta pHOM \pm 0.08\Delta pH \bullet cl\text{-}5.6SMPpH$$

Their R^2 were high and highly significant with values of 0.775, 0.873 and 0.894 recorded. These equations (Table 8) are suitable for virtually all soil particle size classes because they include all the affecting soil parameters. Nevertheless testing for all factors, especially buffer pH is relatively expensive in terms of facility, time and money. It is easier to assemble data for pH, OM and clay from routine soil testings and therefore the equations that don't involve buffer pH measurement are more preferable. Depending on the predominant soil types in an area or zone these equations can be evaluated and confirmed for various soils through liming trials and crop yield correlation experiments.

Comparison of factors that affect the lime requirement for the two groups of soils are presented in Table 9. For Group A soils with higher clay content, the quantity of lime required to raise the soil pH level to 6.0 and 6.5 by incubation study were 3.48 and 6.56 t ha^{-1}, respectively whereas by calculation the quantity of lime required were, respectively 3.10 and 6.67 t ha^{-1}. For Group B soils with lower clay content, corresponding quantity of lime required to raise the soil pH level to 6.0 and 6.5 by incubation study were 2.96 and 3.95 t ha^{-1} whereas by calculation the quantity of lime required were 2.29 and 4.05 t ha^{-1}. This clearly shows that the more sandy soils (Group B soils) require less lime for a significant rise in soil pH than clayey soils (Group A soils). These facts reflect a need for careful determination of the particle size class of soils before the determination of lime requirements.

Lime requirement study: The incubation study results for the two soil particle-size classes under each of the soil groups A and B are shown on the graphs of Fig. 1a (clay and sandy clay loam) and 1b (sandy loam and loamy sand). The incubation study results provided data for the plotting of the neutralization curves shown at Fig.1a, b, for Groups A and B soils. The two types of soils in each soil group were differently affected in the way lime rates determined pH for Groups A soils, the slope of the Sandy Clay Loam (SCL) sub-group of soils (Fig.1a) is much steeper than that of the clay (CL) sub-group. For the B soil group, the curve of the Loamy Sand (LS) soils subgroup (Fig. 1b) likewise rises more sharply than that of the Sandy Loam (SL) sub-group. The implication is that wherever sand content is higher smaller units of lime increment will produce larger increases in soil than where clay content is higher. The curves under the more sandy soils also begin to flatten at a lower lime rate (6 t ha^{-1}) than those under the more clayey soils, which begin to flatten only at the higher lime rate of 8 t ha^{-1}.

Figure 2a, b show the neutralization curves for each of the two groups as a whole (A and B). The figures presented further confirm the general effects of particle size on the lime requirements of soils. The sandier group B soils show very steep rise in pH as lime rate increased and the flattening of the curve does not occur until pH 9.0. Equivalent rise in soil pH under the more clayey group A soils is slower and almost sigmoid. Maximum pH rise occurs at the lower level of pH 8.0. This is indicative of a lower buffering capacity of sandy than clayey soils.

DISCUSSION

This study has highlighted the range of properties that characterize the soil types that are predominant in Cross River and Akwa Ibom States. The ranges of the soil properties observed are the usual values commonly observed for tropical rain forest zones. A review of the soil test values reveals the strong influence that parent materials, topography and climate of each area have contributed to the soils. These data are useful for many purposes in the areas of research, teaching and farming. The group A soils predominant in Cross River State, formed from basement rock complex and volcanic ash show higher fertility potential than the group B soils formed mostly from coastal sands and shale. Owing to higher clay content, the soils of this zone also indicate higher buffering capacities and higher lime requirements[19]. For the Akwa Ibom and southern areas of Cross River (group B), the more acid, more sandy soils show low buffering capacity and thus low lime requirement. The assays of nutrients are low and thus a higher level of fertility management is required.

The soil pH range with a mean value of 5.4 obtained in this study confirmed the description of predominant soil types of the study area as 'acid' [20]. The low level of organic carbon and total nitrogen typifies the common characteristic of the hot and humid tropics by reason of the very rapid rates of organic matter mineralization. This is in conformity with the findings of many studies who reported that these soil types are generally poor in nutrient assay[3-5,7,8,20].

Available P comparatively, tested low in the clayey group A soils, mostly because of the fixation of P in Ca-clay mineral complexes, whereas the B group of soils P being derived mostly from microbial mineralization of organic matter rather tested high, being little fixed by Al and Fe above pH 5.0[21]. Crop cultivation in Obubra, Ikom and parts of Akamkpa, Ugep and Obudu LGAs usually requires P fertilization. The soils of these LGA's are high in clay, Ca, Mg and K. Test results for the B group soils, which predominate in Akwa Ibom State, reflected higher levels of P but very low levels of K, Mg and even Ca. Similar results have been reported in the acid sand soils grown with garden egg[8]. Phosphate availability was highest between the pH range of 5.5-7.0. Fixation problems are usually lowest in this pH range. The most important fertility source for the B group of soils is obviously the organic matter content of the soils, whereas in the A group it is both organic matter and clay. The predominance of 2:1 layer clays in soils derived from basement rock complex and volcanic ash parent materials will abundantly supply cationic nutrients[22].

The factors of soil pH, buffer pH, OM and clay content constituted the primary determinants of lime requirement for these soils. Once information on soil properties is available such data can be plugged into the equations to obtain the lime requirement for the desired pH change. The equations are set for the target pH levels of 5.5, 6.0 and 6.5. Some equations are more appropriate for certain soils or soil groups, depending on which determinant factors are more prominent in such soils. The correlation matrices for the two groups of soils have shown the functional relationships between and among soil properties and also indicated those soil factors that most affect soil pH and lime requirement.

The importance of other soil properties, apart from pH, reflects why the lime requirement is not so simple to determine. Most examples of the acid sandy soils tested in this experiment, although more acidic than the loamy and clayey soils, have relatively low lime requirements on account of their low buffering capacities. Based on the study, both the equations and the curves derived are useful tools for quick determinations of lime requirements.

CONCLUSION

This study revealed that the creation of model equations through multiple regressions has provided a simple method for calculating lime requirements for different soils once soil test data are determined for either a particular soil or similar soils. The factors of soil pH, buffer pH, OM and clay content constituted the primary determinants of lime requirement and the equations are set for the target pH levels of 5.5, 6.0 and 6.5.

SIGNIFICANCE STATEMENT

This study has discovered a simple method for calculating lime requirements for different soils once soil test data are determined that can be beneficial in managing acidic soils. This is a simplified, quick and easily affordable process for the management of acidic soils. This study will help the researcher to uncover the critical areas of avoiding over liming that many researchers were not able to explore. Thus a new theory on the development of a lime requirement equation for different soil types may be arrived at.

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