AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture

B. SECONDARY: Fertilizers

2. TITLE AND SUBTITLE

Liming of highly weathered soils of the humid tropics

3. AUTHOR(S)

Amedee, Gaston; Peech, Michael

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1975	8 p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Cornell University, Department of Agronomy, Bradfield Hall,
Ithaca, New York 14853

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(In Agronomy paper no. 1113)
(Based on the first author's dissertation, available in full: PN-AAA-952)

9. ABSTRACT

The validity of the current practice of using KCl-extractable aluminum for evaluating the lime requirement of acid tropical soils was examined using Ap and B2 horizons of highly weathered soils from six different locations in Brazil, Colombia, and Puerto Rico. The amount of Al (III) removed even upon exhaustive extraction by 1 N KCl greatly underestimated the amount of $CaCO_3$ that was found to react with the soils upon equilibration of the soils with an excess of $CaCO_3$ at the partial pressure of CO_2 of the air. The exchange acidity as determined by the $BaCl_2$-triethanolamine method, however, was found to agree closely with the maximum amount of $CaCO_3$ decomposed by the soils, especially in those that were known to contain aluminous chlorite. Contrary to expectation, the cumulative amounts of Ca^{2+} removed, upon successive extractions with water, from the highly weathered soils of the humid tropics were found to be smaller than that removed from a New York soil. The concentration of Ca^{2+} in the aqueous extracts (Ca^{2+}) was found to follow the relation: $(Ca^{2+}) = K\theta/(1 - \theta)$ in which θ is the degree of Ca^{2+} saturation of the soil and K is the hydrolysis constant. There was no indication of fixation of Ca^{2+} into nonexchangeable forms.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAC-527	

12. DESCRIPTORS

Humidity
Liming
Tests
Tropics
Weathering

13. PROJECT NUMBER

14. CONTRACT NUMBER: CSD-2834 211(d)

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

LIMING OF HIGHLY WEATHERED SOILS OF THE HUMID TROPICS[1]

GASTON AMEDEE AND MICHAEL PEECH

Cornell University, Ithaca, New York

Received for publication January 28, 1975

ABSTRACT

The validity of the current practice of using KCl-extractable aluminum for evaluating the lime requirement of acid tropical soils was examined using Ap and B2 horizons of highly weathered soils from six different locations in Brazil, Colombia, and Puerto Rico. The amount of Al (III) removed even upon exhaustive extraction by 1 *N* KCl greatly underestimated the amount of $CaCO_3$ that was found to react with the soils upon equilibration of the soils with an excess of $CaCO_3$ at the partial pressure of CO_2 of the air. The exchange acidity as determined by the $BaCl_2$-triethanolamine method, however, was found to agree closely with the maximum amount of $CaCO_3$ decomposed by the soils, especially in those that were known to contain aluminous chlorite.

Contrary to expectation, the cumulative amounts of Ca^{2+} removed, upon successive extractions with water, from the highly weathered soils of the humid tropics were found to be smaller than that removed from a New York soil. The concentration of Ca^{2+} in the aqueous extracts (Ca^{2+}) was found to follow the relation: $(Ca^{2+}) = K\Theta/(1 - \Theta)$ in which Θ is the degree of Ca^{2+} saturation of the soil and K is the hydrolysis constant. There was no indication of fixation of Ca^{2+} into nonexchangeable forms.

INTRODUCTION

Highly weathered soils of the humid tropics are acid and highly leached, and thus differ greatly from most soils of the temperate regions. A great majority of these highly weathered soils are classified as Oxisols and Ultisols in the U.S. Soil Taxonomy (Soil Survey Staff 1970) and contain kaolinite, gibbsite, goethite, and other hydrated iron and aluminum oxides as the major components of the clay fraction. Such soils have relatively low cation exchange capacity of which aluminum ions account for a large proportion. Also, the exchange acidity constitutes a major proportion of the cation exchange capacity. Moreover, owing to the presence of the large amounts of iron and aluminum oxides, some of these soils may have a net positive charge at low pH values (Van Raij and Peech 1972) and are unable to retain cations.

The pH-dependent acidity is an important component of the soil acidity. Many soils found in the humid tropics are known to contain pedogenic aluminous chlorite exhibiting pH-dependent acidity (De Villiers and Jackson 1967) which has a great capacity to react with lime. In general, calcium carbonate is added to acid soils to neutralize soil acidity. There is no general agreement on the method for determining the lime requirement of highly weathered soils. It is generally agreed that accurate measurement of the maximum amount of $CaCO_3$ that needs to be applied to obtain optimum crop yields is very difficult. In general, liming recommendations are based on raising soil pH to some specific value. Soil pH value alone, however, is not a good criterion for liming recommendations because of the variation of the exchange capacity of soils. Many methods have been proposed for measuring the lime requirement of soils. Since in acid soils, the

[1] Agronomy Paper No. 1113, Department of Agronomy, Cornell University, Ithaca, N.Y. 14853. Supported by a grant to Cornell University from the U.S. AID under the Institutional Grants Program established by section 211(d) of the Foreign Assistance Act of 1961 as amended in 1966.

aluminum ion is the most abundant cation and largely responsible for soil acidity, many investigators (Kamprath 1970; Reeve and Sumner 1970) have suggested that lime should be added to acid soils in amounts equivalent to neutralize the exchangeable aluminum as determined by 1 *N* KCl. Surprisingly enough, some soils of the humid tropics are known to have only a very small amount of salt-extractable Al(III) even at low pH values. Hence, lime requirement for these soils, as estimated by this method, would be considered minimal. Moreover, the exact significance of the Al(III) extractable by 1 *N* KCl has been questioned (Amedee and Peech 1976). Perhaps a more important consideration is that applications of such minimal amounts of lime would have a very insignificant effect in increasing the effective cation exchange capacity of these soils with very low inherent capacity to retain cations such as K^+ and NH_4^+ applied as fertilizer salts.

In many soils of the temperate regions, it is known that Ca^{2+} applied as $CaCO_3$ is held very strongly by the permanent negative charges of the mineral colloids. Very little of the Ca^{2+} moves to lower depths in the profile. In highly weathered soils where the negative charge is mainly pH dependent, it has been reported that Ca^{2+} and other cations are not held as strongly as in their counterpart soils of the temperate regions (McLean 1971; Sawhney and Norrish 1971; Kamprath 1972). Also, appreciable losses of Ca^{2+} by leaching have been reported in soils of the humid tropics (Mahilum et al. 1970). Other investigators (Mikami and Kimura 1964; Uehara et al. 1972) have presented some evidence that Ca^{2+} can be "fixed" into nonexchangeable form by the highly weathered soils. The purpose of this investigation was to study only the chemical aspects of liming soils of the humid tropics, particularly their reactions with $CaCO_3$, and evaluation of several common laboratory methods for determining the lime requirement of soils. Also, an attempt was made in the present study to determine the fate of Ca^{2+} applied as $CaCO_3$ to soils of the humid tropics.

MATERIALS AND METHODS

Description of soils

Soil samples collected for this study comprised the Ap and B2 horizons of highly weathered soils from six different locations in Brazil, Colombia, and Puerto Rico, known to represent extensive areas of potentially productive agricultural soils. One sample from the plowed layer of a New York soil was also included for comparison. Soil names used in this study were adapted from the U.S. Soil Taxonomy (Soil Survey Staff 1970). A description and some chemical characteristics of these soils are given in Table 1.

Comparison of soil acidity as determined by 1 N KCl and $BaCl_2$-TEA methods with the maximum amount of $CaCO_3$ found to react with the soils

Determination of exchangeable aluminum by 1 *N* KCl: The aluminum extractable by 1 *N* KCl was determined by Yuan's procedure (Yuan 1959). A 10-g sample of soil was mixed with 50 ml of 1 *N* KCl in a 125-ml Erlenmeyer flask and allowed to stand for a period of one hour with intermittent shaking. The mixture was filtered through a 4.25-cm Buchner funnel fitted with Whatman No. 32 filter paper. Additional KCl solution was leached through the soil, in small portions at a time, until 225 ml of the extract had been collected. The extract was transferred to a 250-ml volumetric flask and made up to volume with 1 *N* KCl. Two 100-ml aliquots were transferred into 500-ml Erlenmeyer flasks, boiled for a few minutes to expel CO_2, and then cooled to room temperature. The first aliquot was titrated with standard NaOH to the phenolphthalein end point for total titratable acidity ($H^+ + Al^{3+}$). To the second 100-ml aliquot of the extract, 10 ml of 4 percent NaF solution was added and the mixture was again titrated to the phenolphthalein end point. This second titration gives only the amount of exchangeable H^+. The amount of exchangeable Al^{3+} was obtained by difference between the total acidity and exchangeable H^+.

Determination of exchange acidity by $BaCl_2$-TEA method: Exchange acidity was determined by $BaCl_2$-triethanolamine method (Peech 1965). A 10-g portion of soil was mixed with 100 ml of 0.5 *N* $BaCl_2$-TEA extracting solution adjusted to pH 8.0. The mixture was allowed to stand overnight and filtered through a 4.25-cm Pyrex Buchner funnel fitted with Whatman No. 32 filter paper. A volume of 250 ml of leachate was collected. The exchange acidity was determined by titrating with standard HCl using a

TABLE 1

Description and some chemical characteristics of the soils studied

Soil no.	Soil name	Depth	Organic matter	pH in		Exchangeable	
				H_2O	0.01 *M* $CaCl_2$	Ca^{2+}	Mg^{2+}
		cm	%			me/100 g	me/100 g
1	Acrohumox-Ap (Brazil)	0–20	2.93	5.01	4.30	1.93	0.40
2	Acrohumox-B2 (Brazil)	200–230	0.57	4.95	4.25	0.03	0.08
3	Haplustox-Ap (Colombia)	0–15	3.41	4.15	3.95	0.07	0.06
4	Haplorthox-B1 (Puerto Rico)	61–91	1.09	5.00	4.25	0.50	0.52
5	Tropohumult-B1 (Puerto Rico)	61–91	0.59	4.61	4.00	1.60	0.20
6	Haplustox-Ap (Brazil)	0–15	3.40	4.75	4.20	0.05	0.07
7	Haplustox-B1 (Brazil)	45–60	1.50	5.25	4.55	0.03	0.04
8	Haplustox-Ap (Brazil)	0–15	3.52	4.35	4.00	0.04	0.05
9	Haplustox-B1 (Brazil)	45–60	1.74	4.85	4.05	0.03	0.03
10	Fragiochrept-Ap (New York)	0–15	3.23	4.40	4.00	0.99	0.21

mixed indicator of bromcresol green and methyl red; 250 ml of the extracting solution was titrated to the same end point. The difference between the amount of acid required to titrate the blank and the soil extract represents the amount of exchange acidity.

Determination of the maximum amount of $CaCO_3$ that can react with the soils: A known excess amount of $CaCO_3$ was mixed with 20 g of soil in a 50-ml beaker. After moistening with 20 ml of H_2O, the soils were allowed to equilibrate with $CaCO_3$ at the partial pressure of CO_2 existing in the atmosphere and at a temperature of 25°C for 10 weeks with alternate wetting and drying and occasional mixing. After equilibration of the soils with $CaCO_3$, the amount of residual $CaCO_3$ was determined by the Scholleberger method (Allison and Moodie 1965). The amount of $CaCO_3$ that had reacted with the soil was found by subtracting the amount of residual carbonate found from the amount originally added to the soil.

Results and discusion

The amounts of acidity estimated by the different methods are shown in Table 2. The amounts of $CaCo_3$ found to react with the soils after incubation for 10 weeks with an excess of precipitated $CaCO_3$ were much higher than the exchangeable aluminum content as determined by extraction with 1 *N* KCl, in many instances by more than threefold. They were found to be in better agreement, however, with the exchange acidity as determined by the $BaCl_2$-triethanolamine method, especially for soils 3, 4, 5, and 10 which were known to contain aluminous chlorite.[2] The KCl-extractable acidity greatly underestimated, whereas the exchange acidity by the $BaCl_2$-triethanolamine method tended to overestimate, the lime requirement of most of the soils examined in this study. Inasmuch as the method of equilibration of the soils with $CaCO_3$ is too tedious for routine use, the $BaCl_2$-triethanolamine method should provide a satisfactory benchmark for the full lime requirement of these soils. The actual amount of $CaCO_3$ to be applied will vary depending upon the crop to be grown (Pearson 1975) and the type of soil. Also it should be obvious that the effective cation exchange capacity of some tropical soils can be markedly increased by liming as can be seen from the data given in Table 2. Many investigators (Bornemiza et al. 1967; Kamprath 1971), however, have reported that liming of

[2] Personal communication by Dr. R. M. Weaver.

TABLE 2

Comparison of the maximum amount of $CaCO_3$ found to react with acid soils with the exchange acidity and the amount of exchangeable aluminum

Soil no.	Soil name	1 *N* KCl-extractable Al (III)	Exchange acidity by $BaCl_2$-TEA	Amount of $CaCO_3$ that reacted with soil
		me/100 g	me/100 g	me/100 g
1	Acrohumox-Ap	0.90	9.90	7.79
2	Acrohumox-B2	0.30	6.70	4.63
3	Haplustox-Ap	3.90	18.70	15.40
4	Haplorthox-B1	4.12	16.70	15.53
5	Tropohumult-B1	11.03	20.60	18.62
6	Haplustox-Ap	0.75	13.10	8.24
7	Haplustox-B1	0.15	8.70	4.95
8	Haplustox-Ap	2.25	15.80	9.82
9	Haplustox-B1	1.86	12.10	8.60
10	Fragiochrept-Ap	3.38	16.40	14.86

certain tropical soils to high pH values results in adverse effects, contrary to the results obtained on most acid soils of the temperate regions. There are many theories advanced in attempt to explain the over-liming injury (Schuffelen and Middleburg 1954; Nye 1966; Pratt et al. 1969). Some investigators have suggested that liming causes a deterioration of the structure of the soils of the humid tropics. Others have maintained that liming of tropical soils decreases the availability of some nutritive elements. The real cause of this adverse effect remains to be demonstrated and probably varies with different soils.

FATE OF CALCIUM APPLIED AS $CACO_3$ TO ACID TROPICAL SOILS

Methods and experimental procedures

Preparation of Ca^{2+}-saturated soils: A 60-g sample of soil was mixed with amounts of $CaCO_3$ equivalent to the maximum amount of $CaCO_3$ that had been found to react with the moist soils upon incubation for 10 weeks. The $CaCO_3$-treated soils were moistened and allowed to react for the same period of time with alternate wetting and drying. At the end of the reaction period, the pH values were measured in H_2O and in 0.01 *M* $CaCl_2$. In another method, the soils were treated with $CaCO_3$ as described above, moistened with water, saturated by bubbling CO_2, and evaporated to dryness on a steam bath at 60°C. Again, the pH values were measured as previously described.

Study of loss of adsorbed calcium by leaching: Prepared fully Ca^{2+}-saturated soils were subjected to a series of successive extractions with water to simulate the losses of Ca^{2+} by leaching under field conditions. A 7.5-g sample of soil was mixed with 30 ml of distilled water in a 50-ml polycarbonate centrifuge tube and centrifuged at 18,000 rpm for 20 min in a Sorvall RC2-B refrigerated centrifuge maintained at 25°C. The supernatant solution was decanted, and the extraction procedure was repeated eight times.

Although irrelevant to the object of this study, it should nevertheless be of interest to note that the color of the aqueous extracts became increasingly more yellow upon successive extraction of the soils with water. This increase in the intensity of the yellow color was especially pronounced in about the third extract apparently due to mobilization of Fe(III), as determined by the $\alpha\alpha'$-dipyridyl method, especially in the limed surface soils, indicating that the color must have been due in part to mobilization of some organo-Fe(III) complex after removal of the soluble salts present in the soil. The exact mechanism of this mobilization of Fe(III) in limed surface soils is not known, but this phenomenon may be of interest in studies of soil genesis.

After extraction with water, the soil sediment was saved for the determination of exchangeable Ca^{2+}. The extracts were evaporated to dryness on a steam hotplate after addition of 3 ml of 1:1 HCl. This was followed by the addition of 1 ml of HNO_3 and 5 ml of 30 percent H_2O_2 and evaporation to dryness again. The residue

of salts was taken up with 1 *N* HCl containing 0.5 percent La^{3+}, and the volume was made up to exactly 10 ml. The concentration of Ca^{2+} in the extracts was determined by atomic absorption using a Perkin Elmer model 290B spectrophotometer.

Results and discussion

The pH values of soils incubated in the presence of sufficient amount of $CaCO_3$ required to fully saturate the soils, as measured in H_2O and in 0.01 *M* $CaCl_2$, are shown in Table 3. It will be noted that a good agreement was found between the pH values of soils prepared by both methods.

The cumulative amounts of Ca^{2+}, expressed in me per 100 g of soil, have been plotted in Fig. 1 as a function of the number of extractions. The cumulative amounts of Ca^{2+} removed after eight successive extractions varied widely with different soils, ranging from 0.7 to 4.2 me of Ca^{2+} per 100 g of soil. This variation in the cumulative amounts of Ca^{2+} removed was largely due to differences in the amounts of Ca^{2+} removed in the first three extractions, after which the rate of removal upon further extraction was essentially the same for all soils

TABLE 3

Comparison of pH values of Ca^{2+}-saturated soils as prepared by two methods

Soil no.	Soil name	Amount of $CaCO_3$ applied	Ca^{2+}-saturated soils as prepared by			
			Incubation		Evaporation on steam bath	
			pH in			
			H_2O	.01 *M* $CaCl_2$	H_2O	0.1 *M* $CaCl_2$
		me/100 g				
1	Acrohumox-Ap	7.79	7.10	6.60	7.09	6.80
2	Acrohumox-B2	.63	7.30	6.95	7.40	6.95
3	Haplustox-Ap	15.40	7.55	7.00	7.29	6.85
4	Haplorthox-B1	15.53	7.31	7.20	7.50	7.05
5	Tropohumult-B1	18.62	7.05	6.91	7.25	6.95
6	Haplustox-Ap	8.24	7.16	6.61	7.16	6.50
7	Haplustox-B1	4.95	ND*	ND*	7.58	6.81
8	Haplustox-Ap	9.82	6.86	6.40	6.89	6.38
9	Haplustox-B1	8.60	7.60	6.90	7.20	6.78
10	Fragiochrept-Ap	14.86	ND*	ND*	7.20	6.80

* Not determined.

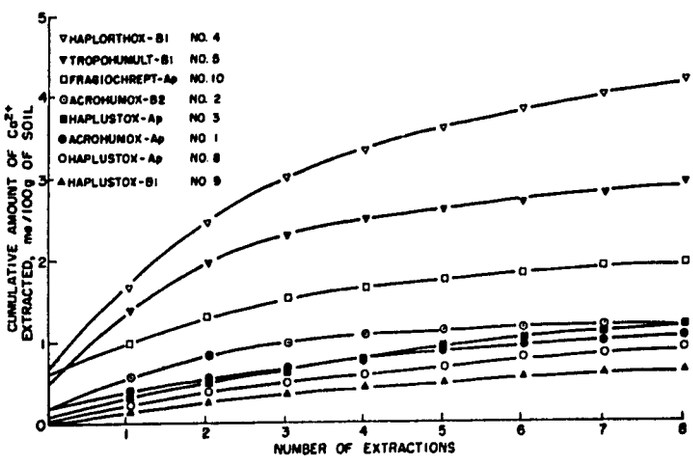

FIG. 1. Loss of adsorbed Ca^{2+} upon successive extractions with water.

with the exception of Soil 4. Contrary to expectation, the cumulative amounts of Ca^{2+} removed from the highly weathered soils of the humid tropics were smaller than that removed from a New York soil, No. 10.

Theoretical considerations of hydrolysis of Ca^{2+} upon successive extraction of the soil with water

The hydrolysis of adsorbed Ca^{2+} can be represented as follows:

$$(RO^-)Ca^{2+} + 2HOH \rightleftarrows 2ROH + Ca(OH)_2 \quad (1)$$

in which R represents Fe(III) or Al(III). Since in highly weathered soils, the charge is solely determined by potential determining ions and Ca^{2+}-soil and $Ca(OH)_2$ are completely dissociated, the net reaction for the hydrolysis of the adsorbed Ca^{2+} can be written:

$$RO^- + HOH \rightleftarrows ROH + OH^- \quad (2)$$

and the equilibrium constant is given by

$$K = \frac{[ROH][OH^-]}{[RO^-]} \quad (3)$$

in which $[RO^-] = [Ca^{2+}] = Ca^{2+}$ adsorbed in me per 100 g of soil,

$$\text{or } [Ca^{2+}] = \theta(CEC) \quad (4)$$

where θ is the degree of calcium saturation and CEC is the cation exchange capacity, and $[ROH] = [H^+] = H^+$ adsorbed in me per 100 g of soil, or

$$[H^+] = (1 - \theta)\ CEC \quad (5)$$

Also, one may substitute $(Ca^{2+}) = (OH^-)$ which is the concentration of Ca^{2+} in solution, expressed in me per liter. Hence

$$K = \frac{(1-\theta)(CEC)(Ca^{2+})}{\theta(CEC)} \quad (6)$$

and

$$K = \frac{(1-\theta)(Ca^{2+})}{\theta} \quad (7)$$

or

$$(Ca^{2+}) \text{ in solution} = K\frac{\theta}{1-\theta} \quad (8)$$

Initially, $\theta = 1$ since $[Ca^{2+}] = CEC$. Thus, the concentration of Ca^{2+} in solution should be proportional to the degree of Ca^{2+} saturation of the soil or, more correctly stated, directly proportional to the quotient $\theta/(1-\theta)$. It should be noted that $\theta/(1-\theta)$ decreases very rapidly with decreasing degree of Ca^{2+} saturation of the soil. The hydrolysis constant K can be calculated for each of the soils upon progressive extraction with water using Eq. (8) in which the concentration of Ca^{2+} in solution is expressed in milliequivalents per liter. In Fig. 2, the concentration of Ca^{2+} in the successive extracts has been plotted against the value of $\theta/(1-\theta)$. The hydrolysis constant is given by the slope of the line. It should be obvious from Fig. 2 that the hydrolysis constant varied widely with different soils (0.01 to 0.19). Essentially the same value for the hydrolysis constant of adsorbed Ca^{2+} was obtained by the dilution method.[3]

RECOVERY OF ADSORBED Ca^{2+}

Determination of exchangeable Ca^{2+} by extraction with 1 N KCl: Following eight successive extractions of the Ca^{2+}-saturated soils with water in the study of hydrolysis of the adsorbed Ca^{2+} described in the preceding section, the soils were extracted successively nine times with 1 N KCl and the clear supernatant solutions were collected in 250-ml volumetric flasks. The concentration of Ca^{2+} in the KCl extracts was determined by atomic absorption. The total amount of Ca^{2+} removed by extraction with water and KCl is considered to be exchangeable. The difference between the total amount of Ca^{2+} applied, including the initial exchangeable calcium content of the soil, and the exchangeable calcium extracted with water and 1 N KCl is considered as Ca^{2+} "fixed" by the soil. Because of the large relative error arising from substraction of two large quantities to obtain a small one, the Ca^{2+} remaining in the soil following extraction with 1 N KCl was determined directly by extracting the soil with 6 N HCl as described below.

Determination of residual calcium after exhaustive extractions of the soils with water and 1 N KCl: Following extraction of the soils with water and 1 N KCl, the soils were transferred to a 150-ml beaker and digested with 30 ml of 6 N HCl for 2 hr on a steam plate. The soil suspensions were then filtered through a 4.25-cm Pyrex glass Buchner funnel fitted with a Whatman

[3] G. Amedee. 1974. Liming of highly weathered soils of the humid tropics. Ph.D. thesis, Cornell University, Ithaca, New York.

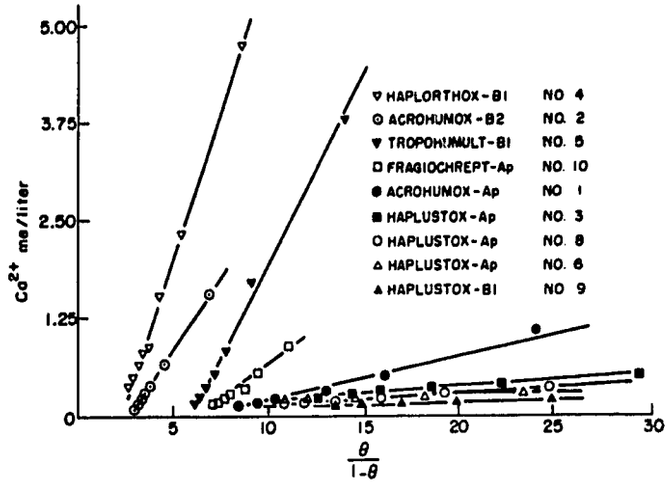

FIG. 2. Concentration of Ca^{2+} in successive aqueous extracts of soils as a function of $\theta/(1-\theta)$.

TABLE 4

Removal of adsorbed Ca^{2+} upon extractions with water and 1 N KCl, and fixation of Ca^{2+} by the soils

Soil no.	Soil name	Initial exch. Ca^{2+}	Ca^{2+} extracted by		Ca^{2+} remaining in soils after extractions		Ca^{2+} "fixed"
			H_2O	1 N KCl	limed	unlimed	
		me/100 g	me/100 g	me/100 g	me/100 g	me/100 g	me/100 g
1	Acrohumox-Ap	9.72	1.08	7.50	0.71	0.27	0.44
2	Acrohumox-B2	4.66	1.20	3.25	0.06	0.02	0.04
3	Haplustox-Ap	15.47	1.22	12.33	1.04	0.08	0.96
4	Haplorthox-B1	16.03	4.15	10.91	0.46	0.06	0.40
5	Tropohumult-B1	20.22	2.87	16.67	0.27	0.02	0.25
6	Haplustox-Ap	8.29	0.88	6.83	0.42	0.03	0.39
8	Haplustox-Ap	9.86	0.92	8.54	0.35	0.03	0.32
9	Haplustox-B1	8.63	0.66	7.37	0.36	0.02	0.34
10	Fragiochrept-Ap	15.85	1.94	12.00	1.76	0.66	1.10

No. 32 filter paper, and the filtrate was made up to volume. A 20-ml aliquot was evaporated until the solution became very viscous, then it was transferred into a 250-ml separatory funnel with Teflon stopcock using enough additional 6 *N* HCl to effect the transfer. The iron dissolved by HCl was removed by extraction with diethyl ether and the resulting solution was transferred to a 150-ml beaker and carried through the same procedure described in the determination of Ca^{2+} by atomic absorption. A correction was made for the native nonexchangeable calcium present in the soil by subjecting the unlimed soils to the same exhaustive extraction with 1 *N* KCl to remove the exchangeable Ca^{2+}, followed by digestion with 6 *N* HCl and carried through exactly the same procedure described for the limed soils. The difference between the amounts of Ca^{2+} extracted by 6 *N* HCl from the limed and the corresponding unlimed soil was considered as "Ca^{2+} fixed" by the limed soils.

The total initial exchangeable Ca^{2+}, which includes the initial exchangeable Ca^{2+} content of the soil plus the amount of Ca^{2+} applied as $CaCO_3$, the amount of Ca^{2+} recovered by extraction with water and 1 *N* KCl, and the amounts of Ca^{2+} fixed by each soil are given in Table 4. It will be noted from the results in Table 4 that, with the exception of two soils, Nos. 3 and 10, the amount of Ca^{2+} found "fixed" into nonexchangeable form was less than 0.5 me per 100 g and is hardly significant. Thus, there is little evidence to indicate that the highly weathered soils of the humid tropics have

the capacity to fix calcium into nonexchangeable form.

REFERENCES

Allison, L. E. and C. D. Moodie. 1965. Carbonate. [*In* C. A. Black (ed.). Methods of Soil Analysis. Part 2. Agronomy 9: 1379-1396. Am. Soc. of Agron. Madison, Wis.]

Amedee, G. and M. Peech. 1976. The significance of KCl-extractable aluminum as an index to lime requirement of soils of the humid tropics. Soil Sci. 121: 227-233.

Bornemiza, E., F. A. Laroche, and H. W. Fassbender. 1967. Effect of liming on some chemical characteristics of a Costa Rica Latosol. Soil Crop Sci. Soc. Fla. Proc. 27: 219-226.

De Villiers, J. M. and M. L. Jackson. 1967. Aluminous chlorite origin of pH dependent cation exchange capacity variations. Soil Sci. Soc. Am. Proc. 31: 614-619.

Kamprath, E. J. 1970. Exchangeable aluminum as a criterion for liming leached mineral soils. Soil Sci. Soc. Am. Proc. 34: 252-254.

Kamprath, E. J. 1971. Potential detrimental effects from liming highly weathered soils to neutrality. Soil Crop Sci. Soc. Fla. Proc. 31: 200-203.

Kamprath, E. J. 1972. Soil acidity and liming. Soils of the humid tropics. Report of committee on tropical soils. Pp. 136-149. National Research Council.

Mahilum, B. C., R. L. Fox, and J. A. Silva. 1970. Residual effects of liming volcanic ash soils in the humid tropics. Soil Sci. 109: 102-109.

McLean, E. O. 1971. Potentially beneficial effects from liming. Chemical and physical. Soil Crop Sci. Soc. Fla. Proc. 31: 189-196.

Mikami, D. T. and H. S. Kimura. 1964. Special features of lime deficient tropical soils. Hawaii Farm Sci. 13: 10-11.

Nye, P. 1966. African experience of the use of fertilizers in the production of basic food crops. Soil Crop Sci. Soc. Fla. Proc. 26: 306-312.

Pearson, R. W. 1975. Soil acidity and liming in the humid tropics. Cornell Int. Agri. Bull. 30. New York State College of Agriculture and Life Sciences, Cornell University, Ithaca, N. Y.

Peech, M. 1965. Exchange acidity. [*In* C. A. Black (ed.). Methods of soil analysis. Part 2. Agronomy 9: 905-913. Am. Soc. of Agron., Madison, Wis.]

Pratt, P. F., F. F. Peterson, and C. S. Holzhey. 1969. Qualitative mineralogy and chemical properties of a few soils from São Paulo, Brazil. Turrialba 19: 491-496.

Reeve, N. G. and M. E. Sumner. 1970. Lime requirements of Natal Oxisols based on exchangeable aluminum. Soil Sci. Soc. Am. Proc. 34: 595-598.

Sawhney, B. L. and K. Norrish. 1971. pH-dependent cation exchange capacity: Minerals and soils of tropical regions. Soil Sci. 112: 213-215.

Schuffelen, A. C. and H. A. Middleburg. 1954. Structural deterioration of lateritic soils through liming. Trans. Fifth Int. Congr. Soil Sci. 2: 158-165.

Soil Survey Staff. 1970. Selected chapters from the unedited text of Soil Taxonomy of the National Cooperative Soil Survey. Soil Survey, Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C.

Uehara, G., L. D. Swindale, and R. C. Jones. 1972. Mineralogy and behavior of tropical soils. Conference held at the International Institute Tropical Agriculture, Ibadan, Nigeria.

Van Raij, B. and M. Peech. 1972. Electrochemical properties of some Oxisols and Alfisols of the tropics. Soil Sci. Soc. Am. Proc. 36: 587-593.

Yuan, T. L. 1959. Determination of exchangeable hydrogen in soils by a titration method. Soil Sci. 88: 164-167.