TECHNICAL NOTE

NO. 3

LIMING AND THE SOILS OF LAM NAM OON

SAKON NAKON, THAILAND

SEPTEMBER 1980

ISSUED BY

CENTER FOR RURAL DEVELOPMENT

LOUIS BERGER INTERNATIONAL, INC., U.S.A.

UNDER CONTRACT WITH MINISTRY OF

AGRICULTURE AND COOPERATIVES OF THE

KINGDOM OF THAILAND

Work Performed By

ERROLL D. COLES

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PART I

BACKGROUND

AS

RELATED TO SOILS OF AREA

A. Introduction

The Lam Nam Oon Integrated Rural Development Project (LNO) is located in amphoes* Phang Kone, Pannanikom, and Muang, Changwat Sakon Nakon, Thailand. It comprises a dam, reservoir, and main-secondary canal system that will provide irrigation water to approximately 220,000 rai of small farm holdings. About 10,000 farmers reside in the area.

Begun thirteen years ago, the infrastructure parts of the project are now almost completed. In order to develop efficient on-farm water delivery systems and water/farm management practices in the area, The Royal Thai Government has programmed US$43,800,000 for special work in the area during a five-year interval.

Of this amount, US$4,500,000 comprises funds borrowed from the United States of America in order to finance technical assistance, equipment, and local development costs.

Starting October 12, 1979 the American consulting firm, Louis Berger International, Inc. was employed under contract to provide technical advisory services for the project. These advisory services are for the cooperating agencies comprising: The Ministry of Agriculture And Cooperatives; Royal Irrigation Department (R.I.D.), Community Development Department (C.D.), Department of Agriculture (D.A.) and Department of Agricultural Extension (D.O.A.E.).

The contractor is tasked with responsibility for designing and testing on-farm water delivery systems in the Lam Nam Oon (LNO) area. This has to be in the context of an irrigation system that will deliver dry season water in sufficient quantities to cultivate field crops; but it will not deliver enough water for allowing cultivation

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* Administrative Sub-Districts of a Changwat (Province)

of large areas of dry season rice.

The soils of the area are of fragile fertility, and as will be noted below, may not be well suited to the high yielding cultivation of field crops.

Recognizing this situation, the Louis Berger consultants have made a preliminary investigation of the problem. Mr. Erroll Coles, an Agricultural Engineer with extensive experiences in Africa, The Middle East, and Indonesia, has done this work and formulated some initial recommendations.

B. Project Data Resources - Soils

A reconnaissance soil survey was conducted throughout the project area in 1962[1/] and this survey formed the basis for the identification of the main soil series. The soil series were described in broad context and no attempt was made to detail taxinomic correlations. A very detailed land classification was based on this soil survey. The procedures detailing the land classification, soil analytical data and other pertinent information, including a set of maps, is given in the Land Classification Report, Volume 1 and 2, prepared by Engineering Consultant's Inc. 1973.

These two sets of documents provide:

1. Soil Maps

   A set of 10 maps showing the land class boundaries and interpretative soil series boundaries, plotted to a scale of 1:20,000, and other simple detail of the project area.

1/ Sarot Montarkun 1962. Report on the Preliminary Soil Survey of the Lam Nam Oon Irrigation Area. Misc. Report No. 4. Dept. of Rice R.I.D.

These maps are suitable for identifying soil series in the field.

2. Soil Analysis

A total of 3356 soil profiles were examined and samples taken. Approximately 400 of the profiles' analyses are given in the Land Classification Report (Volume 2. Appendix D). The analyses include both the chemical analysis for the main soil constituents and physical analysis of the soil properties.

3. Soil Series

The reconnaissance soil survey identified 13 soil groups, 12 series and one non-soil group consisting of borrow pits and spoil material. The soil series are described according to the national soil survey procedures.[2/] The soil series occurring within the project area are listed in Table 1 together with their international classification nomenclature.

The predominant soil series on the project is the Roi Et series (an Ultisol) followed by Korat series (an Ultisol) and the remaining 10 soil series make up the remaining area. The areas occupied by the respective soil series are shown in Table 1.

The primary soil series all belong to the Ultisol order and display a similar set of characteristics to soils of a similar kind found throughout the humid tropics of

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2/ Moorman, F.R., Sarol Montrakun and Sarnarn Panichapong. Soils of Northeast Thailand, a key to their identification and Survey. Department of Land Development, 1964.

Africa, the Americas and other parts of Southeast Asia. The local soils display similar agronomic problems to those soils occurring elsewhere too.

4. Salinity

The soil analyses indicate that about 11,500 rai or 5.25% of the project area present incipient salinity. The electric conductivity (EC x 10^3) of most of the analyses is below the critical level of 2.5 but the sodium content of the saturation estimate of 192 soil profiles shows fairly high levels. In some samples this is above 100 meg./litre and ranges on an average between 10 and 15 meg./litre. The Sodium Absorption Ratio (SAR) tends to exceed the threshold limit of 15 for many of the samples. The predominant anion is the chloride radicle with subservient sulphate and bicarbonates.

The effect of salinity on dry season crops will be enhanced by the low exchange capacity of the soils and light sandy texture of these soils.

The Roi Et and Ubon series tend to be more affected by salinity than the other series. The shallow Sakon series could become saline under intensive irrigated dry land cropping.

However, the salinity problem will be examined in another Technical Note at a later date.

PART II

CRITICAL ISSUES

CONCERNING DEFINITION

OF

SOIL PROBLEMS - LAM NAM OON

A. Chemical Characteristics

From the large number of soil analyses reported it is possible to deduce a number of characteristics about these soils. Firstly, the low pH values are indicative of acid soils; the range of pH values for the surface layers are shown in Table 2 for a number of profiles.

Second, the low Cation Exchange Capacity (CEC) values and the small amount of clay, seldom exceeding 15% in the main soil series, are indicative of soils of low fertility, combined with a low organic matter content, usually below 1.0%.

There does not seem to be a clearcut relationship between the soil paste pH and the Exchangeable Aluminum, as plotted in Figure 1. The values all cluster between pH 4.5 and 5.5. Aluminum saturation does the same thing. Plotting the same values for two layers of the Roi Et series displays the same effect, in Figure 2. However, plotting Exchangeable Al against C.E.C. demonstrates a relationship which may be curvilinear but should be linear between these two variables.[3/]

The soils of the project area do not differ from similar soils found in other countries with similar climatic regimes. These soils are highly leached. They are derived from coarse sedimentary material and there is very little base activity in them. Generally, they do have a fairly high ratio of Exchangeable Aluminum and critical aluminum toxicity indexes for most of the soils (Table 2, Column 10). It may be noted here that high aluminum saturation can have definite inhibiting effects on crop growth.

3/ Engineering Consultants Inc. Land Classification Report, Appendix B, 1973.

B. Liming And pH.

The Land Classification Report argues that these soils have very high lime requirements. This is based on the proposition that the critical issue is to supply sufficient lime (calcium carbonate) to raise the pH of the soils to a value of pH 7. The amount of lime required to do this as estimated in the Report is based on the "Neutralizing Calcium Requirement" which in turn is based on titration tests (see Page 7, Volume II, Appendix B for a full description of the test procedure).

Such a method of determining liming requirements is questionable. It tends to give very high rates of application per farm unit. Attempting to neutralize soil to a level of pH 7 would be very difficult to accomplish from a costing point of view. Achievement of such a level as pH 7 would also cause definite micro - nutrient difficulties in most field crops.

It should also be pointed out that, in general, optimum pH levels vary from crop to crop but the ideal level usually ranges between 5.5 and 6.5.

C. Liming And Aluminum Toxicity.

Experimental work conducted on similar Ultisols and Oxisols 4/ in other tropical countries have indicated that responses to lime application has been attributed to the reduction of Exchangeable Aluminum (Al) particularly with characteristic Ultisol soils with low C.E.C. levels and with low pH levels. An expression has been

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4/ Lathwell, D.J., Crop Responses to Liming of Ultisols and Oxisols Cornell International Bull. 35 Cornell University N.Y. 1979.

developed to express the level of Al toxicity of these soils,*

$$\text{Al Index} = \frac{\sqrt{Ca}}{\sqrt[3]{Al} \qquad \sqrt[6]{\Sigma CEC}}$$

where Ca = exchangeable calcium meq/100 gm.

Al = " aluminum meq/100 gm.

Σ CEC = sum of the exchangeable cations, meq/100 gm.

The index is noteable in Table 2, Column 10. The toxicity level increase towards zero and the threshold level would be about 1.0 to 1.15.

Aluminum saturation is expressed as the ratio of Exchangeable Aluminum to Exchangeable Calcium plus Magnesium. This ratio is shown in Table 2, Column 9. The threshold levels for this ratio may be as low as 10% but not exceeding 15%. This will depend on the sensitivity of the particular crop plants.

D. Contrasts in Liming Rates.

It has been suggested that liming rates (L.R) for tropical Ultisols having a low pH, low C.E.C. and high aluminum saturation may be based on the following equation

$$L.R. = (2 \times \text{Exchangeable Al}) + [2 - \text{Exchangeable (Ca + Mg)}]$$

* See Reference 4/

The ion are expressed in meq/100 gm. of soil. The rates based on this equation are given in Table 2, Column 11, and in graph A on Figure 4.

The liming rates based on the titration method used in the E.C.I. report (Appendix B)* are shown in Table 2, Column 12.

The equation used to calculate the lime requirement is given here,

$$L.R. = \frac{\text{Soil depth x bulk density x NCR}}{\text{lime percentage x lime efficiency.}} \times \frac{\text{---}}{\text{--- equivalent weight factor x 1600.}}$$

$$= \frac{15 \times 1.45 \times NCR \times 50 \times 1600}{90 \times 100}$$

$$= 193.3\ NCR.\ \text{in kg/rai.}$$

The value of NCR is given in Table 2, Column 4.

It should be noted that this equation is based on amount of lime needed to increase the pH upto 7. The values in Column 12 have been plotted against the corresponding Exchangeable Aluminum values in graph B, Figure 4.

Comparing this curve to the curve in A above considerable more lime would be needed to achieve the required neutralization of Exchangeable Aluminum.

An alternative equation used to determine the lime requirement for a number of Oxisol soils in Natal[5/],

$$L.R. = -0.393 + 3.353\ E.Al.$$

E.Al. = exchangeable aluminum, meq/100 gm.

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* See reference 3.

5/ Reeve, M.G. and Sumner, M.E. Lime Requirements of Natal Oxisols based on Exchangeable Aluminum. Soil Sci. Soc. Amer. Proc. Vo. 1 34 1970.

This equation is plotted in graph C., Figure 4 and it gives a higher estimate of lime than A but slightly less than B.

The curve plotted in graph D, Figure 4 is based on the equation normally used in temperate regions to estimate lime needed to neutralize the pH to 7.

$$L.R. = 1792.6 \, [\text{pH } 7.0 - \text{pH (buffered)}],$$

in kg per rai. This curve indicates the very high application rates recommended compared to the amounts estimated by means of the curves in graphs A and C.

E. Observations

Obviously, careful experimental determinations must be conducted on the project soils at LNO in order to obtain similar relationships as those described above before reaching any definite conclusions. The curves calculated here may lay a basis for these determinations.

The threshold limits for unimpaired crop growth and yields at LNO may be about 0.2 meq/100 gm. of Exchangeable Aluminum.

The amount of lime required to neutralize aluminum toxicity to this threshold limit is about one quarter to one sixth of the quantity needed to raise the pH from 4.5 to 6.5 with an E.Al equal to 2.0 meq/100 gm., the lime requirement is shown in the following example.

Graph A		440 kg/rai
Graph B	(1200 - 200)	1000 kg/rai
Graph C	(1020 - 40)	980 kg/rai
Graph D	(pH 6.5 = 1400-) (pH 4.5 = 4500)	3100 kg/rai

A = 4			
Cumulative days	3 & 4	3 & 4	3 & 4
A	0.731	1.465	2.117

Other factors that should be taken into account when interpreting lime requirements in these soils is the clay and organic matter. The kaolinitic clay is not very active and low in content, so is the organic matter. Both these factors can have definite effects on crop production under the existing soil status.

From an examination of the profile characteristic in Table 2, some soils show a definite increase in E.Al and decreasing Ca and Mq. with an increasing depth, this is particularly noticeable with the Alluvial series, No. 19, (Profiles 6-MS, 7 MS and 13 MS) the same feature occurs in most of the profiles though it is not so apparent. This factor is significant when the surface soil is removed in the current deepcut land levelling operations in some areas of LNO.

In order to overcome the adverse effects of removing the top layers, lime should be applied at the appropriate rate to correct aluminum toxicity in the lower layers and this lime should be ploughed in to a depth of 25 to 35 cm. This should be done, in any case, because lime or calcium carbonate is not very mobile in soils because of its low solubility. Little benefit will be obtained by applying lime to the surface. To obtain the full effect the lime must be worked into the soil, at least into the effective root zone of the crops. The greatest benefit is obtained by deep ploughing, upto 40 cm. This may present much difficulty for successful field crop production, which will really benefit from the use of lime, on this project.

Generally, crop response to lime applications is not only involved in neutralizing soil acidity, as would be the case in temperate climatic soils, but rather to counteract the effects of excess Exchangeable Aluminum in these highly leached soils, of the humid tropics. Furthermore, lime should also be used to counteract

the acidulating effects of heavy fertilizer applications particularly from nitrogen fertilizer when applied to HYY which are followed by upland crops. This suggests that, in general, much lower rates of lime application are required in the Lam Nam Oon area.

PART III

CROP RESPONSES AND ALUMINUM TOXICITY

A. Introduction

A preliminary search of the available literature on crop trials carried out in Thailand indicates that no serious work has been done on the effects of aluminum toxicity together with low pH values in these kinds of soils. Considering the size of the Northeast region and its importance as a crop producing area, it is surprising that no experimental work has been instituted to investigate the inter-relationships between low pH, aluminum toxicity and liming. Although Al toxicity does not affect wet rice paddy except when the soils are not flooded, it does seriously inhibit field crop growth and yields. Some crops are not too sensitive to high levels of Al saturation but combined with low pH values, a low C.E.C. and calcium deficiency most crops will exhibit yield suppression. On the other hand, heavy applications of lime are likely to cause micronutrient imbalances such as zinc and molybdenun deficiencies and in some soils manganese toxicity which will lead to reduction in yields too.

Given this situation it may be useful to comment about a number of crop plants now cultivated in the Lam Nam Oon project area. They are mentioned with specific reference to soil factors, prevalent at LNO, which inhibit yields. Their responses to corrective measures in similar soils elsewhere are also mentioned.

B. Wet Paddy Rice

This is not normally affected by low pH; nor by high aluminum toxicity levels because the iron salts in solution tend to precipitate the Al in solution.

C. Upland Rice Or Dry Season Paddy Season Rice

Where low water use or semi-flooding techniques are used, the low pH and high aluminum toxicity of these soils can adverse rice plant yields, in which case, corrective lime applications or the use of leached gypsum applications through the water supply can boost yields.

Investigations, elsewhere, in similar soils have also shown that these types may be severely deficient in available silica.[6/] The role of silica in the rice plant is to increase resistance to blast disease and counteract the adverse effects of iron and manganese toxicity as well as to improve resistance to loding. This is particularly important for upland rice or dry season paddy rice. The threshold levels according to the following table appears to be about 7 mq/100 gm. while at a level of 4 mq/100 gm. severe deficiency occurs. Silica deficiency is corrected by applying basic slag or furnace slag.

Silica Status of some tropical soils (after Kawagachi, 1966)

Region	No. of Soils	Deficient*	Severely** Deficient
Korat	31	24	21
North	10	6	2
Central	46	6	3
West Malaysia	29	8	2
East Malaysia	12	6	3

* deficiency at 7 mq/100 gm.

** deficiency at 4 mq/100 gm.

6/ Kawaguchi K. (1966). Silica Status of some Tropical Soils Jap. Agr. Res. Quart 1.

3. Maize and Sorghum

Experimental work[7/] has shown that maize (or corn) yields increase with lime applications for most tropical soils whenever the pH falls below pH 5 and the Exchangeable Al exceeds 15 percent saturation. These threshold limits also apply to sorghum; but sorghum may be even more sensitive to Al toxicity and acid pH levels than maize. (See Figure 5)

On these grounds, it is possible to explain the poor results of the maize trials within the project area during the 1979, and 1980 dry season. They were obviously affected by low pH and Al saturation percentages in the critical range. Any future trials should take these factors into account and lime should be applied at rates to correct the pH to about pH 5.5 or more economically, to reduce the Al saturation level to below 15 percent or to above 0.2 meq/100 gm. of Exchangeable Al.

E. Soybeans

Significant increases in soybean yields have been obtained by applying lime to tropical acid soils where they are grown; but soybean is also known to be affected by the following factors.

a) Soybean varieties are relatively tolerant to Al toxicity;

b) They are sensitive to manganese toxicity, and

c) Molybdenum availability that interacts strongly with soil pH and this trace element is an important factor in soybean production.

7/ Pearson, R.W. 1975. Soil Acidity and Liming in the Humid Tropics. Cornell International. Agr. Bull. 30 Cornell University, N.Y.

The last two factors though very important to high yield soybean production have not yet been investigated on the LNO project soils and any future trials should take these factors into consideration. These highly leached, acid soils demonstrate that some kinds of trace element deficiency does occur and certain imbalances causing toxicity may also be a factor in not obtaining good soybean yields.

F. Beans

Both dry beans and fresh beans form an important dietary and market crop in the project area. Their yield could be increased because elsewhere on similar soils the response of bean varieties to lime application has been consistent up to a pH of between pH 5.3 to 5.6. Beans are also sensitive to low elemental calcium, below 5 meq/ 100 gm. There also appears to be a close correlation between Al saturation and manganese content in the soils below pH 5.0. The optimum ratio of Ca to Mn in bean leaves has been related at a level of 225.

G. Groundnuts

Groundnuts are highly tolerant of high levels of Al saturation; but are sensitive to low levels of available calcium. This situation probably partially explains the generally good performance of groundnuts in the LNO area during recent trials. They are sensitive to low levels of molybdenum; and the threshold limit appear to be between 6 and 12 meq/100 gms. of available calcium. However, groundnuts grown on highly leached, poorly buffered, tropical soils do respond very positively to small lime applications because of the crops critical

calcium requirements and to the molybdenum and lime interactions.

H. Cotton

Though cotton is not an important crop in the LNO project area so far, trial plantings have been carried out.

Cotton trials elsewhere on similar soils have shown significant yield responses to application of lime and again the response is attributed to Al saturation and the imbalance of micronutrient, caused by the low pH of the soils.[8/] Low available calcium may depress yield too. In the LNO area it appears that the application of lime at prescribed rates would improve cotton yields. Any extensive planting of cotton will certainly require some liming to boost yields.

I. Sugar Cane

Sugar cane might become an important alternative crop to rice on some of the soil groups of the LNO project. If proper varieties were introduced together with good soil management and adequate arrangements for processing/marketing sugar cane might be amongst the best alternative dry season cropping systems, combined with wet season rice at LNO. In this connection, sugar cane tends to be less sensitive to low pH values but significant responses have been obtained to lime applications on leached tropical soils with low C.E.C. and low pH's. The threshold limits seem to be at pH 5 and Al saturations below 15 percent.

8/ See reference 7.

J. Vegetable Crops

Most vegetable crops tend to be adversely affected by the pH and Al status of soils like those in the LNO area. They would benefit from lime applications though these applications should not be excessive, as most vegetables are very sensitive to the effects of micronutrient deficiencies that can be induced by high rates of lime application.

K. Forage Crops

Generally, forage grasses are tolerant of soil acidity and where high rates of nitrogenous fertilizer are applied severe acidity develops and subsequent crops tend to suffer. Responses to lime at rates of two or more tons per hectare have given maximum yields on some tropical soils. However, some grass species are more tolerant to soil acidity than others, yet they have responded to lime applications too.

Forage Legumes are more tolerant of acid soil conditions but their yields are reduced in strongly acid soils especially if manganese is fairly abundant. For the LNO area it would appear that very low rates of liming, from 150 to 250 kg per hectare would be beneficial in improving yields for these kinds of crops. The three species that are recommended for growing on acid tropical soils are stylosanthes, Kudzu (Pueraria phaseoloides) and Centrosema.

L. Conclusions

The judicious application of lime can only be beneficial to crop production on these otherwise very infertile soils; but excessive applications will be detrimental in the short term. However, crop

rotations should be compiled to include crops that will increase the organic matter content of these soils. The present cultural practices, simple ploughing and even hand-hoeing, really precludes the use of green manure crops because of the heavy power requirements needed to turn the crop into the soil. The possibility of using mixed forage grass and legumes may be on alternative which should be investigated. Another alternative is to include sugar cane in the rotation. This would provide large volumes of organic matter by way of its extensive root system. Other crops that may provide high levels of organic matter, combined with lime use, should be investigated, but such crops should also be of economic benefit to the farmer, in other words, a marketable crop.

PART IV

RECOMMENDATIONS

1. It must be emphasized that attempting to apply lime at rates required to return the pH to 7.0 or neutrality would be inappropriate. Crop plants do not thrive at that level. However, they do thrive at a pH of between 5.2 to 6.2 and this is possibly ideal for most plants. Furthermore, the cost of attempting to raise pH to 7 would be expensive. Furthermore, suitable grades of agricultural lime are not available in low-cost, high volume quantities at present. However, dolemitic limestone is being used for aggregate and building stone at the LNO site. This is trucked from west of Udon, a distance of 170 km. It is conceivable that a source of this kind could be used if yield tests convinced farmers that large increases on production could be attained. It is recommended that any trials constantly be based on the assumption that this source could be expected.

2. It will be necessary to carry out a series of properly compiled field trials with a number of different kinds of crops on carefully selected soils. The varieties should comprise a range of those that are affected minimally or modestly by aluminum toxicity and low pH, under irrigated conditions. The soils of these plots should be carefully sampled and analyzed before the trials are planted out. The analysis should include the determination of micronutrients as well. The trials should include the effects of liming, gypsum leaching, and other inputs on yields of various field and other crops in soils of the LNO area under irrigated conditions. However, fertilizer trials may also be included in this work. It is recommended that, not less than two sites should be selected and the trials run for three or more seasons. This work should be supervised by a properly staffed and large institutions to insure continuity and disciplined control

of the trials over the full term of the work. Failure to do this will negate the whole purpose of this rather important investigation into liming of the project soils.

3. It will be necessary to provide a sound basis for future field demonstrations. Therefore, it is recommended that the soils should be sampled and analyzed, together with fertilizer and lime applications on a systematic basis rather than on some rule-of-thumb factor. This will overcome future problems in demonstration work where it is essential to show the farmers exactly what is needed. It will also help in training Kaset Tambols to assist in explaining demonstration results and organizing same.

4. It is recommended that the laboratories carrying out the analysis of the soils be required to use the extraction technique advocated by Skeen and Sumner 1965.[9/]

9/ Skeen, J.B. and Sumner, M.E. Measurement of Exchangeable Aluminum in Acid Soils. Nature, Vol. 208, No. 5011 p. 712. November 13, 1965.

Table

Soil Series of the Lam Nam Oon Project Area.

Mapping	Soil Series	National Soil Groups	Internation Soil Groups		Area if Project		
			Order	Great Group	Ha	Rai	%
10	Non-soil*	-	-		-	-	-
15	Sithon (Lucustrine)	Hydromorphic Alluvial	Entisol	Ustifluvents(?)	1,309	8,683	3.6
19	Alluvial complex (Chiengmai)	Alluvial	Entisol	Typic Ustifluverts	3,448	21,555	8.9
21	Phimai	Hydromorphic Alluvial	Vertisol	Fropaquepts	2,892	18,077	7.5
22	Ratchaburi	ditto	Inceptisol	Aeric Tropaquepts	234	1,463	0.6
25	Udon	Solonchat(?)	Inceptisol	Aeric Halaquepts	320	2,006	0.8
38	Phon Phi Sai	Red Yellow Podsol	Ultisol	Plinthustults	34	213	.09
41	Roi Et	Low Humic Gley	Ultisols	Aeric Palequults	16,920	105,747	43.8
49	Phen	Low Humic Gley	Ultisols	Plinthaquults	460	2,878	1.2
51	Korat	Gray Podsolic	Ultisol	Paleustults	9,917	61,979	25.7
55	On	Low Humic Gley	Ultisols	Plinthaquults	1,514	9,467	3.9
61	Sakon	Groundwater Laterite soils	Ultisols	Haplustults	-	-	-
65	Ubon	Hydromorphic Regosols	Inceptisol	Aquic Dystropepts	1,515	9,467	3.9
					38,645	241,535	100

Soil Profile Characteristics

'rofile No. :oil 'eries	Depth cm.	pH. paste	$Ca(OH)_2$ Meq/100 gms.	C.E.C. meq/100 grm.	Exchangeable Cations meq/100 grm.			Al Saturation	Al Toxicity Index	L R_1	L R_2
					Al	Ca	Ca+Mg	%		Kg/rai	Kg/rai
1	2	3	4	5	6	7	8	9	10	11	12
- MS	0 - 17	4.8	2.2	3.1	0.37	1.1	1.6	18.8	1.21	182.4	425.3
11)	17 - 55	5.0	4.2	5.6	2.0	1.2	2.4	45.5	.65	576.0	812.0
	55 - 86	5.2	-	6.2	1.9	1.2	3.0	38.8	.65	448.0	-
	86 - 119	5.3	-	8.1	1.7	1.7	4.7	26.6	.77	112.0	-
- MS	0 - 23	5.0	1.8	3.4	0.13	1.2	2.0	6.1	1.76	41.6	348.0
11)	23 - 59	6.2	-	-	-	.34	.52	-	-	-	-
	59 - 82	6.3	-	-	-	.09	.39	-	-	-	-
	82 - 133	6.9	-	-	-	.17	.32	-	-	-	-
MS	0 - 16	4.1	6.5	3.7	.08	1.9	4.3	1.83	2.57	-	1256.7
-	16 - 41	5.3	0.7	2.0	0	1.1	4.2	-	-	-	135.3
	41 - 90	5.8	-	-	-	1.9	7.2	-	-	-	-
	90 - 132	6.3	-	-	-	.82	2.0	-	-	-	-
- MS	0 - 10	5.1	1.3	2.6	.27	.09	1.8	28.0	.40	118.4	251.3
	10 - 40	4.9	2.9	5.0	1.6	1.1	2.4	40.0	.25	448.0	560.7
	40 - 75	4.8	-	5.3	2.6	.84	1.7	60.5	.50	880.0	-

rofile No. oil eries	Depth cm.	pH. paste	$Ca(OH)_2$ Meq/100 gms.	C.E.C. meq/100 grm.	Exchangeable Cations meq/100 grm. Al	Ca	Ca+Mg	Al Saturation %	Al Toxicity Index	L R_1 Kg/rai	L R_2 Kg/rai
1	2	3	4	5	6	7	8	9	10	11	12
- MS	75 - 115	5.1	-	6.9	3.4	0.90	2.4	58.6	.46	1024.0	-
- MS	0 - 10	4.2	1.8	4.0	0.26	1.2	1.9	12.04	1.36	99.2	348.0
41	10 - 34	5.1	0.5	2.7	0	1.1	1.7	-	-	-	96.7
	34 - 63	5.5	-	7.4	0	3.8	4.7	-	-	-	-
	63 - 95	6.0	-	-	-	1.2	1.5	-	-	-	-
	95 - 123	6.2	-	-	-	.77	.93	-	-	-	-
- MS	0 - 15	4.9	4.3	4.4	1.3	1.3	1.9	40.6	.82	432.0	831.3
19	15 - 47	5.0	5.8	6.2	3.4	1.0	1.4	70.8	.49	1184.0	1121.3
	47 - 98	5.0	-	8.4	5.4	.43	1.3	80.6	.26	1840.0	-
	98 - 158	5.0	-	9.3	4.7	.49	1.5	75.8	.29	1584.0	-
- MS	0 - 12	4.7	7.4	9.3	1.2	5.0	6.7	15.2	1.45	-	1430.7
19	12 - 36	4.6	7.3	9.8	3.6	2.6	4.9	42.4	.72	688.00	1411.3
	36 - 70	4.6	-	15.0	7.4	3.5	6.3	54.0	.61	1680.00	-
	70 -130	4.5	-	14	7.0	3.2	5.2	57.4	.60	1728.00	-
3 - MS	0 - 15	6.6	-	-	-	1.8	3.0	-	-	-	-

Profile No. Soil Series	Depth cm.	pH. paste	$Ca(OH)_2$ Meq/100 gms.	C.E.C. meq/100 grm.	Exchangeable Cations meq/100 grm. Al	Ca	Ca+Mg	Al Saturation %	Al Toxicity Index	L R_1 Kg/rai	L R_2 Kg/rai
1	2	3	4	5	6	7	8	9	10	11	12
- MS											
51	15 - 53	5.5	1.2	3.2	.05	1.6	2.5	2.0	2.83	-	232.0
	53 - 103	5.0	-	3.5	.42	.95	2.3	15.4	1.06	86.4	-
- MS	0 - 16	4.7	6.6	9.4	1.6	3.7	6.5	19.8	1.13	-	1276.0
21	16 - 50	4.6	10.8	17	4.8	6.3	9.5	33.6	.93	336.0	2088.0
	50 - 86	4.6	-	16	4.2	4.8	8.9	32.1	.86	240.0	-
	86 - 138	4.3	-	22	7.0	4.2	7.3	48.9	.64	1392.0	-
- MS	0 - 16	4.9	1.2	4.9	.79	2.1	3.0	20.8	1.2	86.4	232.0
41	16 - 52	5.1	2.5	4.5	1.3	1.3	2.2	37.1	.81	384.0	480.3
	52 - 80	5.3	-	5.1	2.1	.85	1.5	58.3	.55	752.0	-
	80 - 100	5.6	-	9.8	-	.09	.29	-	-	-	-
- MS	0 - 15	4.9	7.6	16	1.1	8.7	13	7.8	1.80	-	1469.33
21	15 - 55	4.9	-	16	3.0	8.4	12	20.0	1.27	-	-
	55 - 92	4.9	-	17	4.4	6.0	11	28.6	.93	-	-
	92 - 144	4.8	-	20	8.7	5.3	8.8	49.7	.68	1696	-

rofile No. oil eries	Depth cm.	pH. paste	$Ca(OH)_2$ Meq/100 gms.	C.E.C. meq/100 grm.	Exchangeable Cations meq/100 grm.			Al Saturation %	Al Toxicity Index	L R_1 Kg/rai	L R_2 Kg/rai
					Al	Ca	Ca+Mg				
1	2	3	4	5	6	7	8	9	10	11	12
- MS	0 - 16	5.0	2.0	3.8	.29	1.5	2.5	10.4	1.48	12.8	386.7
-	16 - 52	4.8	2.1	3.4	.77	.81	1.8	29.9	.80	278.4	406.0
	52 - 90	5.0	-	3.1	.56	.56	1.7	24.8	.75	227.2	-
	90 - 135	5.1	-	3.8	.80	.76	2.0	28.6	.75	256.0	-
- MS	0 - 20	4.5	14.5	9.9	3.58	3.33	5.35	40.1	.81	609.6	2803.3
9)	20 - 44	4.8	9.4	9.2	5.58	1.06	2.66	67.7	.40	1680.0	1817.3
	44 - 57	5.5	-	6.8	3.49	.79	2.57	57.6	.42	1025.6	-
	57 - 86	5.8	-	20	-	.19	.34	-	-	-	-
	86 - 110	5.6	-	-	-	.18	.34	-	-	-	-
- MS	0 - 14	4.6	9.9	9.8	2.3	5.0	6.6	25.8	1.16	-	1914.0
19)	14 - 42	5.0	8.5	11.0	4.5	2.5	5.1	46.9	.64	944	1643.3
	42 - 73	5.1	-	12.0	7.2	2.0	4.4	62.2	.48	1920	-
	73 - 109	5.0	-	14.0	6.4	2.4	6.6	49.2	.54	1312	-
- MS	0 - 15	4.6	3.7	6.0	.78	1.8	4.1	15.9	1.08	-	715.3
15)	15 - 56	5.3	1.1	6.5	.12	3.0	5.1	2.3	2.57	-	212.7

Profile No. Soil Series	Depth cm.	pH. paste	$Ca(OH)_2$ Meq/100 gms.	C.E.C. meq/100 grm.	Exchangeable Cations meq/100 grm. Al	Ca	Ca+Mg	Al Saturation %	Al Toxicity Index	L R_1 Kg/rai	L R_2 Kg/rai
1	2	3	4	5	6	7	8	9	10	11	12
5 - MS	56 - 95	5.5	-	8.2	.22	4.6	6.7	3.2	2.50	-	-
	95 - 111	5.3	-	4.5	0	2.4	3.4	-	-	-	-
6 - MS	0 - 14	4.6	1.6	2.9	.37	.93	1.6	18.8	1.12	182.4	309.3
41	14 - 32	4.8	1.7	6.0	1.0	1.3	4.3	18.9	.85	-	328.7
	32 - 95	4.8	-	7.0	2.0	1.5	3.8	34.5	.70	352.0	-
	95 - 146	5.1	-	9.7	.66	4.2	6.4	9.4	1.61	-	-
7 - MS	0 - 18	5.1	0.7	3.7	0	.62	1.1	-	-	-	135.3
65	18 - 70	4.5	1.6	5.2	.82	.85	2.8	22.7	.75	134.4	309.3
	70 - 125	4.1	-	9.0	3.5	.50	2.8	55.6	.32	992.0	-
8 - MS	0 - 12	5.1	2.8	6.0	.32	3.5	4.8	6.25	2.03	-	541.3
41	12 - 36	5.4	2.1	8.0	0	5.7	7.1	-	-	-	406.0
	36 - 82	5.3	-	6.1	.12	3.9	5.0	2.34	2.95	-	-
	82 - 130	5.5	-	4.2	.08	2.4	2.9	2.7	2.83	-	-
9 - MS	0 - 16	5.2	2.4	4.3	.11	2.0	3.6	2.9	2.31	-	464.0
51	16 - 48	4.7	3.8	3.7	1.4	.61	1.6	46.7	.56	512.0	734.7

'rofile No. ·oil ·eries	Depth cm.	pH. paste	$Ca(OH)_2$ Meq/100 gms.	C.E.C. meq/100 grm.	Exchangeable Cations meq/100 grm.			Al Saturation	Al Toxicity Index	L R_1	L R_2
					Al	Ca	Ca+Mg	%		Kg/rai	Kg/rai
1	2	3	4	5	6	7	8	9	10	11	12
) - MS	48 - 86	4.6	-	4.0	1.4	.5	1.5	48.3	.50	528.0	-
	86 - 140	4.8	-	5.0	1.5	.36	2.5	37.5	.40	400.0	-
) - MS	0 - 18	5.5	3.5	4.2	.10	2.0	3.2	3.0	2.40	-	676.7
·5)	18 - 60	5.1	1.8	3.9	.45	.8	2.7	14.3	.63	32.0	348.0
	60 - 115	4.8	-	4.1	1.1	.68	2.0	35.5	.63	352.0	-
- MS	0 - 10	5.2	1.7	2.8	.11	.95	1.8	5.8	1.71	67.2	328.7
55)	10 - 28	5.0	1.1	3.4	.23	1.4	2.5	8.4	1.57	-	212.7
	28 - 35	4.9	1.3	4.8	.27	2.2	3.8	6.6	1.77	-	251.3

L. R_1 = liming rates based on equation to counteract aluminium toxicity

L. R_2 = liming rate based on raising soil pH to 7.0.

Table 3

Some Chemical Characteristics of the Various Soil Series

Mapping No.	Soil Series	Depth cm.	Clay %	pH paste	CEC	Exch. Al. meg/100gm
15	Sithon	0 - 15	17.3	4.6	6.08	0.78
		15 - 56	22.9	5.6	6.55	0.12
19	Alluvial Complex	0 - 20	42.3	4.5	9.9	2.10
		20 - 44	45.1	4.8	8.2	4.27
21	Phi Mai	0 - 15	50.8	4.9	15.6	1.35
		15 - 55	64.0	4.9	16.3	3.90
22	Ratchburi	-		-		-
25	Udon (acid - Saline - sodic)	0 - 16	21.9	4.1	5.4	-
		16 - 41	22.2	5.3	10.9	
38	Phon Phi Sai	-		-		-
41	Roi Et (Saline)	0 - 23	2.5	5.0	3.3	-
		23 - 59	6.2	6.2	2.4	-
41	Roi Et	0 - 14	9.5	4.6	2.85	.36
		14 - 32	10.9	4.8	6.00	1.48
41	Roi Et (Acid -	0 - 10	13.1	4.2	3.8	-
	Saline - Sodic)	10 - 34	12.3	5.1	2.5	-
49	Korat	0 - 16	8.1	5.2	4.35	0.08
		16 - 48	13.1	4.7	3.77	1.4
55	On	0 - 10	6.0	5.2	2.80	0.11
		10 - 28	6.7	5.0	3.37	0.23
61	Sakon	-	-	-	-	
65	Ubon	0 - 16	0.6	5.0	3.84	0.10
		16 - 52	8.3	4.8	3.37	0.64
19	Alluvial Complex	0 0 15	13.8	4.9	4.39	
		15 - 47	12.8	5.0	6.20	

Note: This table is compiled from Table XI-4 and XI-10 Land Classification Report. Volume 1.

: This table is not based on an extensive examination of all the analyses and it is only indicative of possible constituent levels.

Figure 1

Distribution of E.Al and pH. Table 1

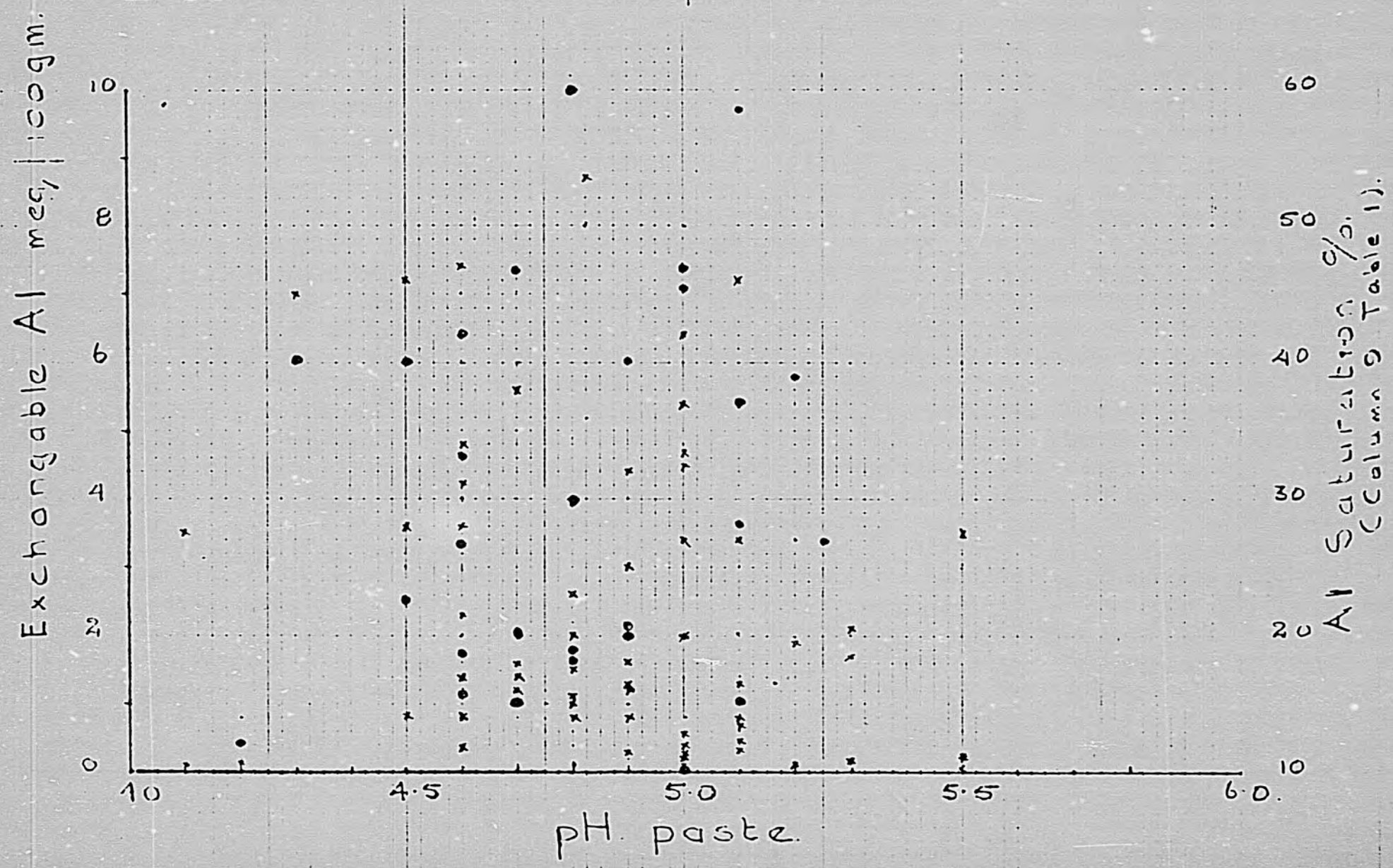
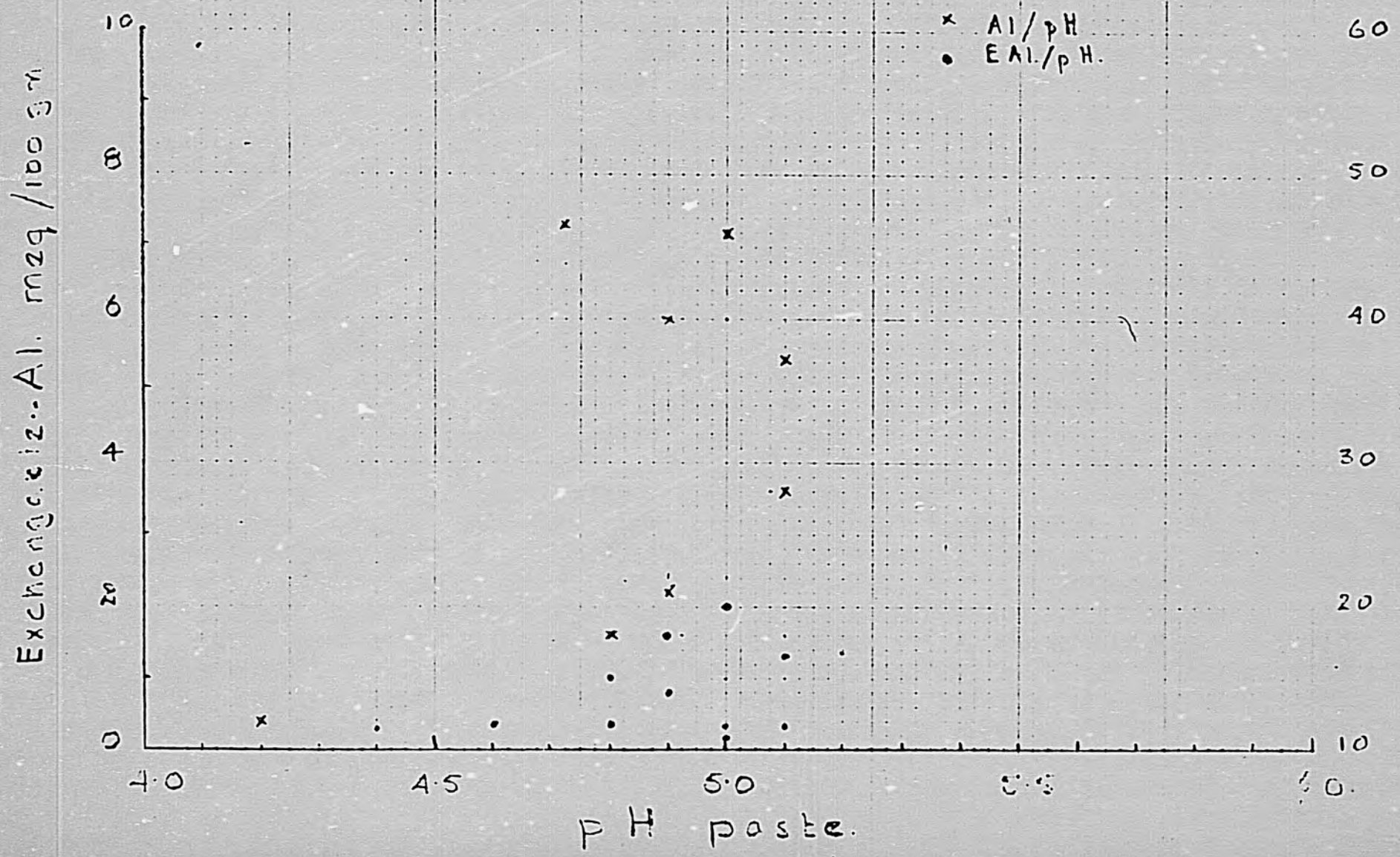


Figure 2

Plot of 1st and 2nd layers of the Roi Et Soils. (N°41)



K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 0706

Figure 3.

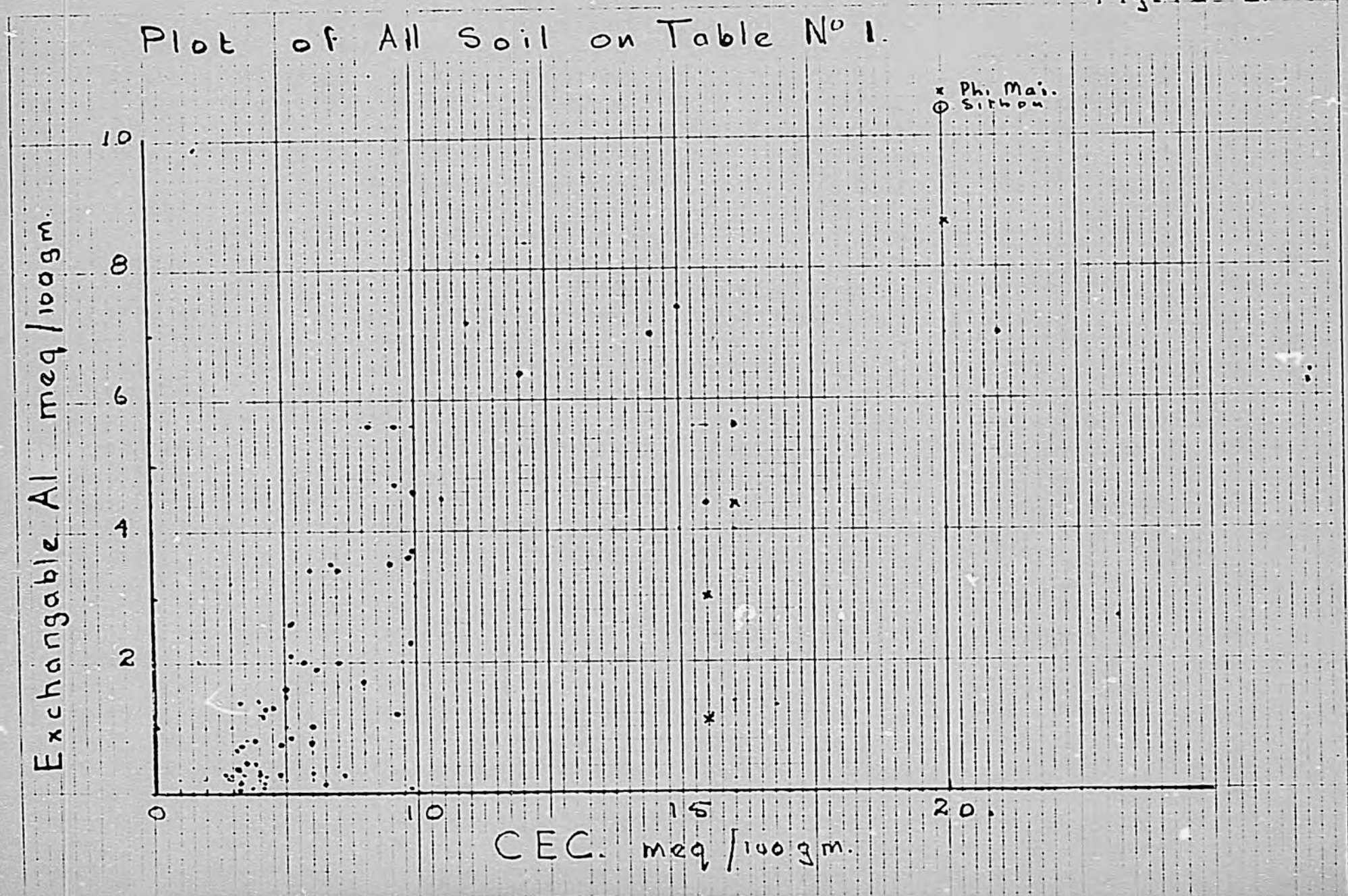
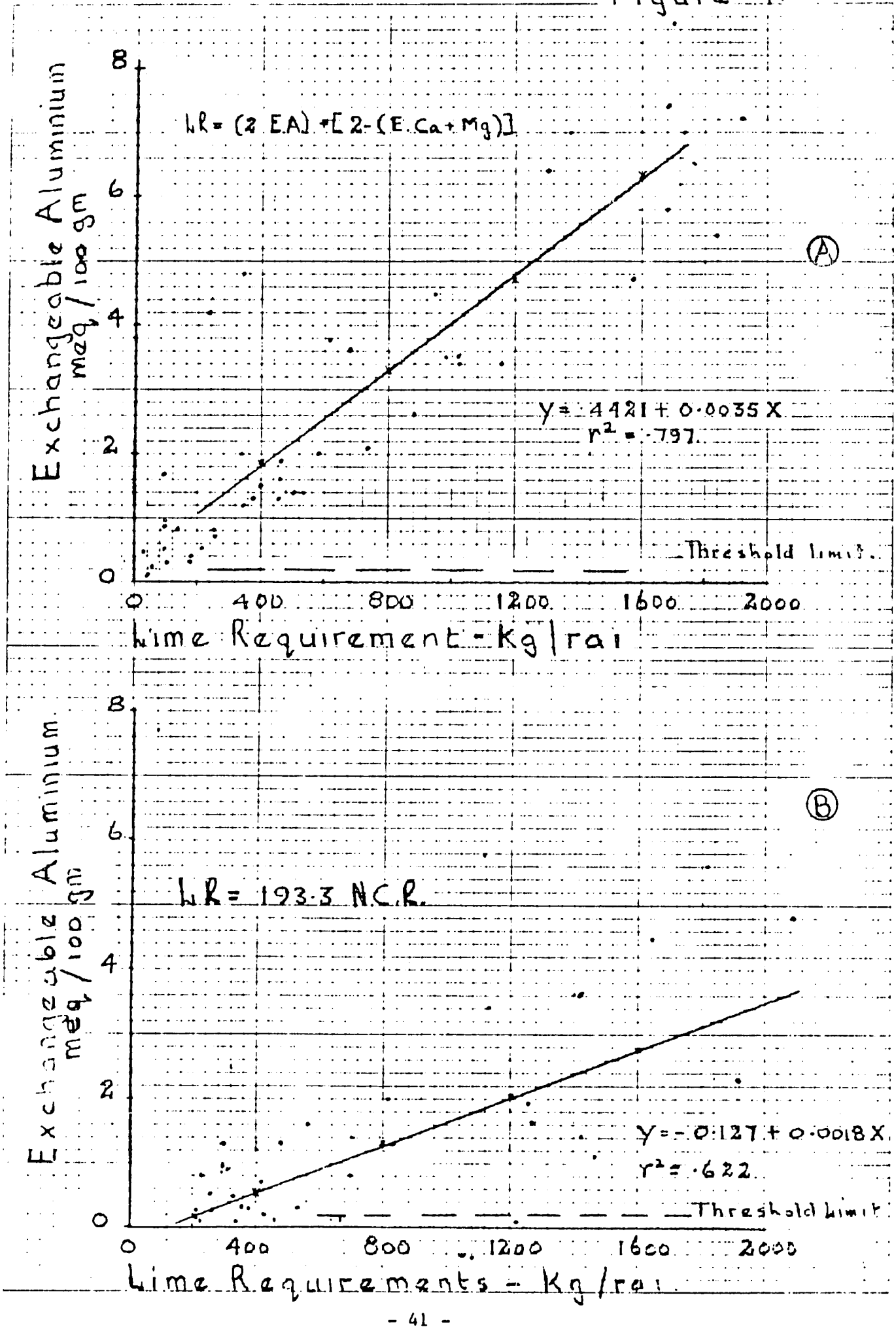
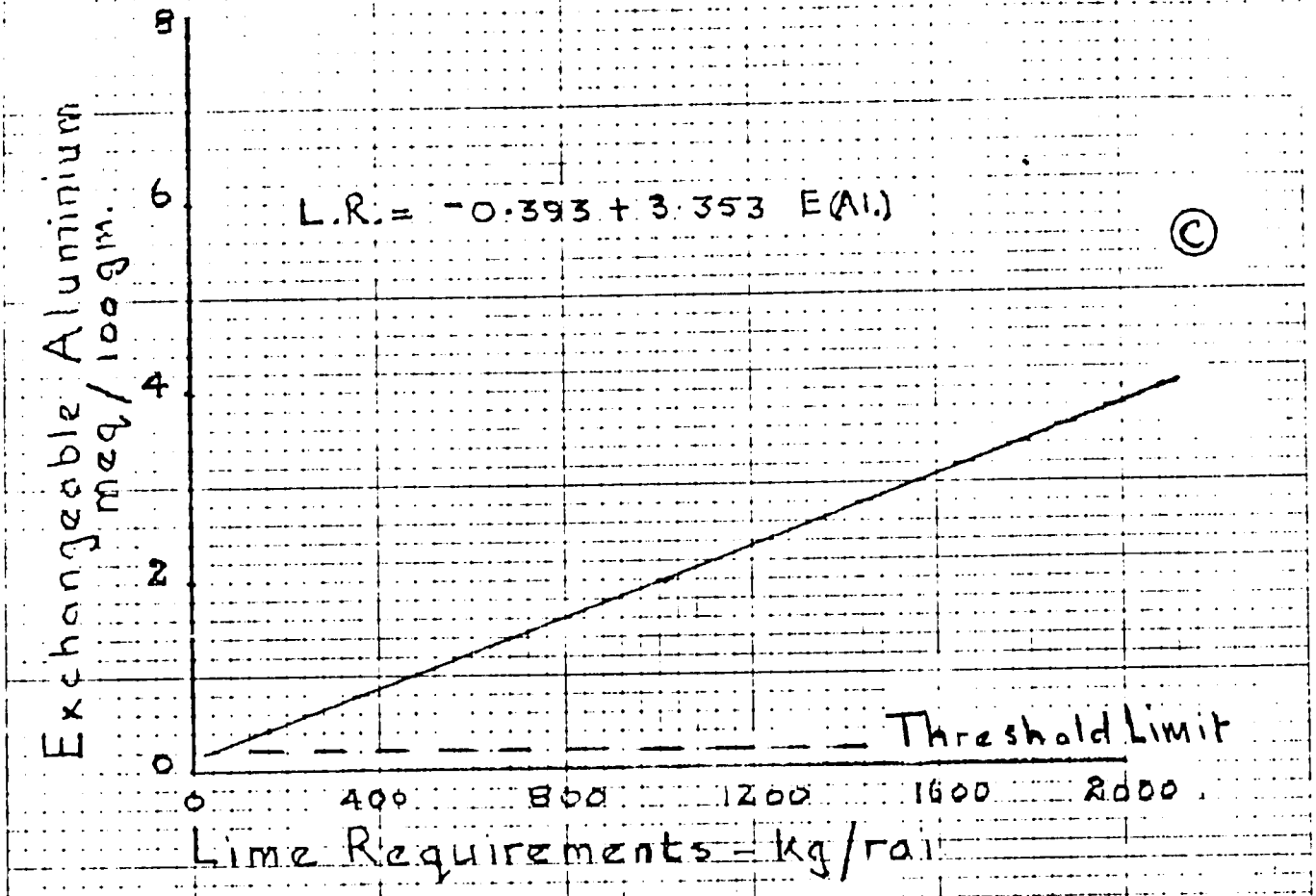


Figure 4.



Exchangeable Aluminium meq / 100 gm
LR = (2 EA) + [2 - (E.Ca + Mg)]
Y = .4421 + 0.0035 X
r² = .797
Threshold limit.
Lime Requirement - Kg/rai
A
Exchangeable Aluminium meq / 100 gm
LR = 193.3 N.C.R.
Y = -0.127 + 0.0018 X
r² = .622
Threshold Limit
Lime Requirements - Kg/rai
B

Figure 4


Exchangeable Aluminium
meq/100gm.
8
6
4
2
0
L.R. = -0.393 + 3.353 E(Al.)
C
Threshold Limit
0
400
800
1200
1600
2000
Lime Requirements - kg/rai

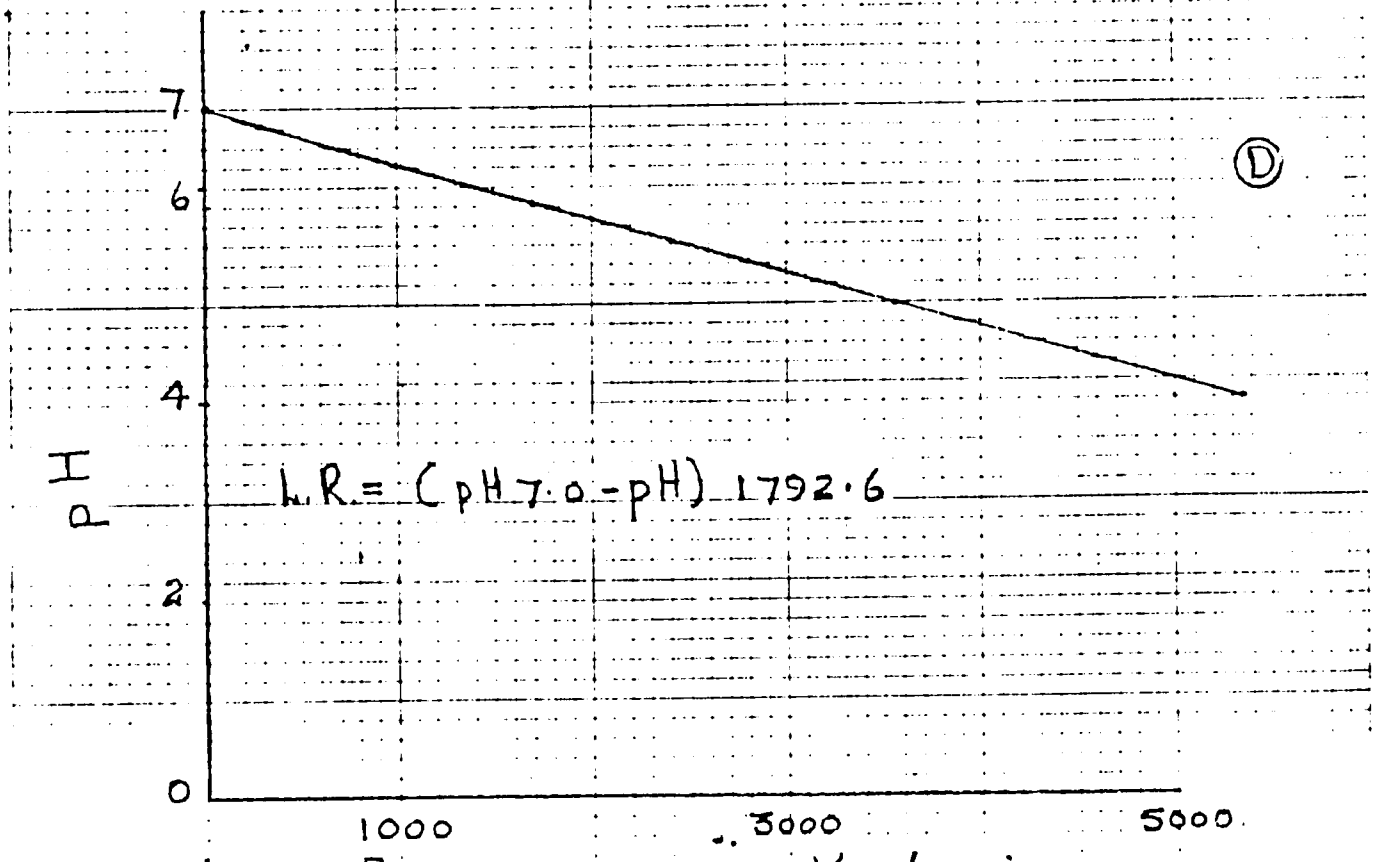
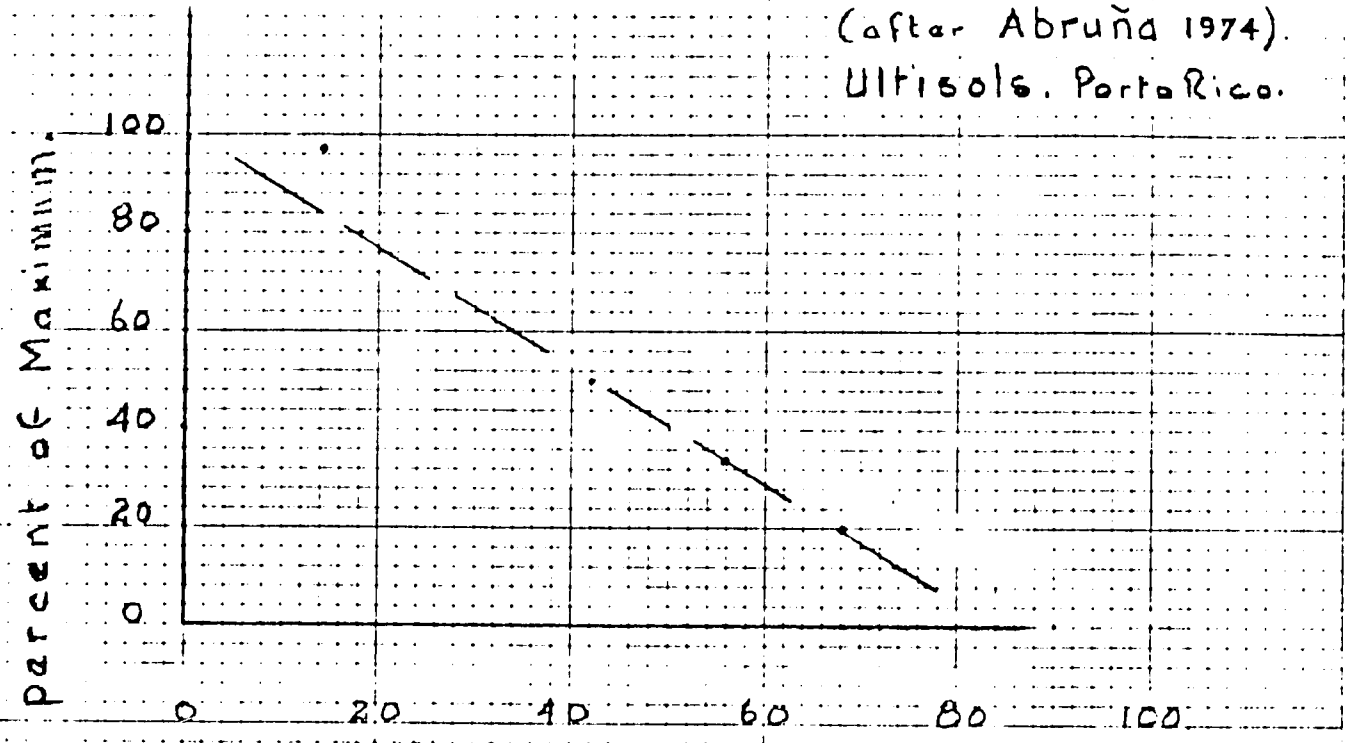
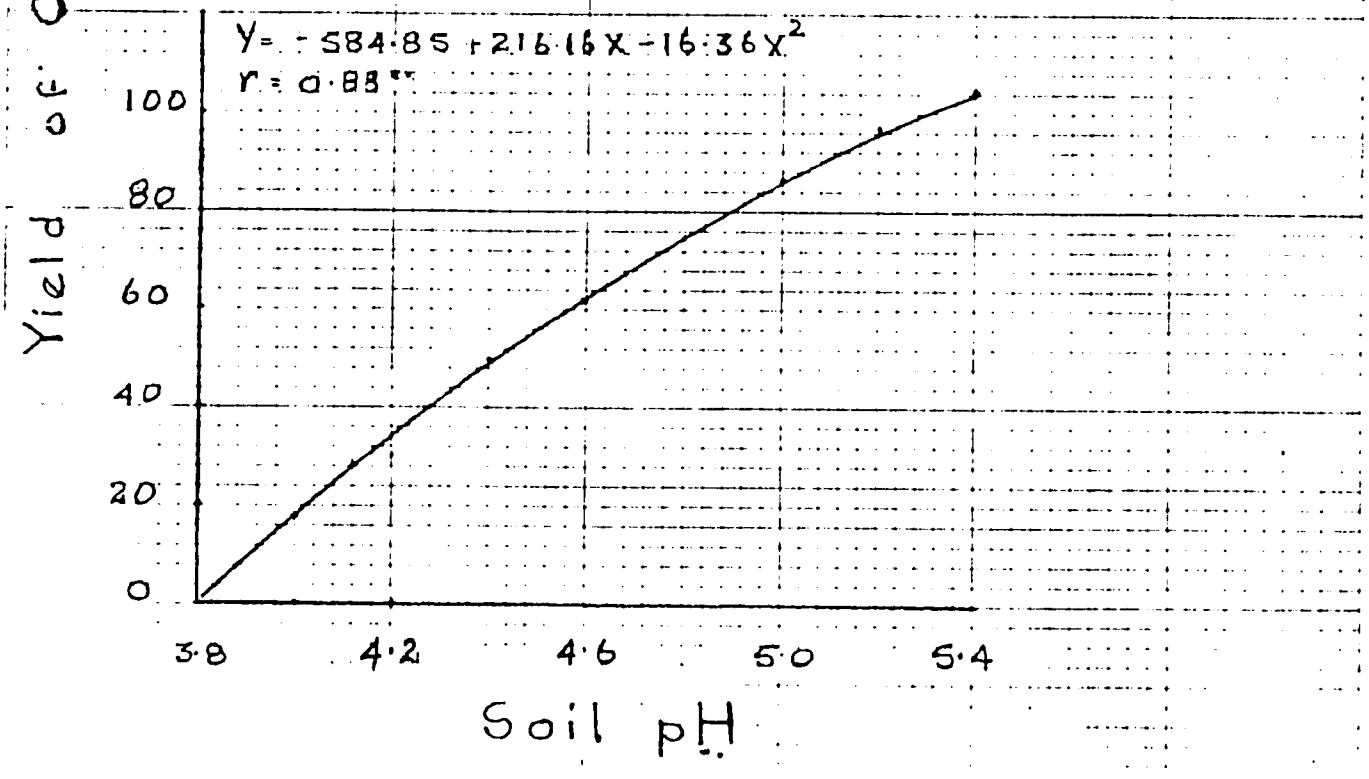

pH
7
6
4
2
0
D
L.R. = (pH 7.0 - pH) 1792.6
1000
3000
5000
Lime Requirements. - Kg/rai

Figure 5

Effect of Al Saturation and pH on Corn Yields.

(after Abruña 1974).
Ultisols. Porto Rico.





AUTHOR

Erroll Dennyse Coles is a Fellow of the Institute of Agricultural Engineers. A graduate of Salisbury Poly-Technic and London University (external studies) he has specialised on surface irrigation systems in Africa, the Near East, and Asia since 1955.

He has been employed by Louis Berger International, Inc. as a Senior Irrigation Engineer since 1976. Assignments have included projects in Iran, Indonesia, Egypt, and - currently - Thailand.