May 28, 1962

To the Graduate Council:

I am submitting herewith a thesis written by Joseph R. Overton entitled "Lime Requirement Studies on Selected Soils." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Dean of the Graduate School

LIME REQUIREMENT STUDIES ON SELECTED SOILS

A Thesis

Presented to

The Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Joseph R. Overton

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CHAPTER I

INTRODUCTION

It is recognized that there are important relationships of lime to soil fertility and crop production and that soils differ in related chemical and physical properties. Recommendations for applications of lime in Tennessee are made for both field and horticultural crops on soils of widely differing properties including differences in parent material, texture, humus content, and clay mineral type. At present, state recommendations for applications of lime are made largely on a basis of pH of the surface soil alone without considering texture, organic matter content, or other soil properties. A "rule of thumb" is used to recommend 2 tons of ground limestone per acre for each pH unit increase desired. This system includes a lime factor of about 2, recommending twice the required amount of calcium carbonate to compensate for coarseness, mixing, time required for reaction, and other factors which would limit the completeness of the reaction.

In the future some soils not now used may be needed for agricultural production, or a more intensive management may be required on many soils than is now practiced. Either situation would tend to require a more precise system of making lime recommendations. The present distribution of soil samples may not represent all the soil conditions of the state, or the degree their future use might indicate. Some reports indicate that following present recommendations does not accomplish the pH adjustment desired. Liming recommendations should give some

consideration to the sub-surface layers of soils within the rooting depths of commonly grown crops.

These possibilities coupled with the considerable differences among soils indicate the desirability of a study of the surface and sub-surface layers of certain differing soils with respect to characteristics affecting lime relationships.

CHAPTER II

REVIEW OF LITERATURE

I. CONCEPTS OF LIME REQUIREMENT

Lime requirement has been variously defined as the amount of lime which must be added to a soil to bring the reaction to neutrality or to some other pH desired; or as the amount of lime required to raise the soil pH one unit; or simply the amount of lime needed to grow a certain crop. Veitch (58) concluded "A soil faintly alkaline from carbonate of lime furnishes the best conditions for the economic production of crops, and the use of any method for estimating the acidity or the lime requirements of soils should be based on this hypothesis." MacIntire (24) defined lime requirement as "the soil's maximum capacity to decompose $CaCO_3$ in the laboratory." Bradfield and Allison (5) defined a "base saturated soil" as "one which has reached equilibrium with a surplus of $CaCO_3$ at the partial pressure of CO_2 existing in the atmosphere and at a temperature of 25° C." Shaw (45) considered these men in agreement in that a "base saturated" soil was one that was in equilibrium with an excess of calcium carbonate. He recognized that the term "exchangeable hydrogen" was similar in connotation to "soil acidity" and "lime requirement."

Coleman and others (7,8) preferred the use of the term "exchange acidity" to "exchangeable hydrogen." They considered that the permanent charge not neutralized by basic metal cations was saturated by aluminum, and the only exchangeable hydrogen in most mineral soils is that which is

neutralized between pH 6 and the pH at the end point of the determination. Truog (57) stated that a pH of 6.5 was favorable for availability of essential elements in soils.

There seems to be wide agreement that a soil nearly saturated with calcium in the field is the result desired. Factors involved in achieving this are type and amount of clay minerals and humus, and status of saturation as to kind and amount of cations. The soil condition desired may depend on the plants to be grown.

Methods used to estimate lime requirement differ in what they measure, the condition of measurement especially pH, degree of precision, and speed and suitability for routine laboratory work. Peech (33) pointed out the need for clearly defined methods so that their results could be better understood. He also saw the need of a greater uniformity among workers as to the methods they used to study lime requirements. Peech and Bradfield (35) indicated the need of learning all the beneficial effects of liming different acid soils in order to properly evaluate the methods used.

II. USE OF pH IN DETERMINING LIME STATUS OF SOILS

Many workers have recognized the widespread use of pH as a criterion of lime status of soils (33,35,45,47,56). Limitations due to variations caused by dilution, presence of electrolytes, carbon dioxide concentration, and clay mineral type have been pointed out (8,33,56). Shaw (45) described difficulties of soil pH measurements which could lead to differences of a few hundred to several thousand pounds calcium

carbonate per acre. pH is a measure of the active acidity, but alone it does not indicate the total or reserve acidity. Several workers have stated that the use of pH would be of greatest value in connection with some other soil property as texture, cation exchange capacity, organic matter and exchangeable calcium (8,35,45,56). Arnon and Johnson (1) indicated that the use of pH required interpretation, and concluded that a hydrogen ion concentration from pH 4 to 8 was not in itself harmful to plants. Peech and Bradfield (35) and Morgan (32) suggested the use of pH with a table of other soil properties such as organic matter and texture.

Since pH is a measure of hydrogen ion concentration, it has a direct relationship to degree of base saturation. This relationship is quite useful in determining lime requirements of soils (8,26,33,56). Neutralization curves of acid soils with calcium hydroxide as proposed by Dunn (11) are widely used (33,49). Such curves show the change in pH with each addition of base, or may be prepared to show the pH-percent base saturation relationship. The addition of base to bring the untreated soil to pH 7 is considered the lime requirement; addition of base to bring an acid washed soil to pH 7 is considered a measure of cation exchange capacity (8). Mehlich (26) and Coleman and Mehlich (8) presented titration curves for soils having certain clay mineral types. Mehlich (26) suggested the use of such curves for regional use in soil classification and determination of lime requirements, but recognized the limitations of application to soils having more than one type of clay mineral. Jones and Hoover (21) prepared neutralization curves of certain soils and compared them to those of Mehlich (26) to classify the clay mineral type

in soils. Neutralization curves with sodium hydroxide give higher pH values than calcium hydroxide at the same degree of saturation. Shaw (48) suggested the use of finely ground calcium carbonate for use in making titration curves.

The use of one generalized neutralization curve for determining lime requirement of all soils of a region implies that all the soils have similar cation exchange capacities and similar neutralization curves. Shaw (47) stated that there was difficulty in estimating percent base saturation within 10 to 20 percent by pH. Hissink (16) recognized the need for considering the percent base saturation of soils in evaluating them.

Coleman and others (7,8) related pH and exchangeable cations to two sources of cation exchange capacity. The permanent charge of clay minerals results from their crystal structure. The pH-dependent charge results chiefly from ionization of hydrogen ions from SiOH groups and does not contribute to the effective cation exchange capacity of said soils. Organic matter has only pH dependent charge resulting from ionization of hydrogen from carboxyl and phenol groups of the organic matter. In this concept the pH at which exchangeable cations and cation exchange capacity are determined, the amount of clay and kind of clay contribute to the values determined.

Several researchers (7,30,31,60) reported that a lower degree of base saturation was required on 1:1 clay mineral types to produce responses of certain plants than for 2:1 types. Coleman, Kamprath and Weed (7) related this to whether the charge was pH dependent or independent.

Shaw (47) suggested the use of pH, the exchange acidity determined by the neutral calcium acetate method, and a soil constant defined as pH at 50 percent base saturation for computing lime requirement to pH's other than 7. Shaw (48) suggested using the exchange acidity by the neutral calcium acetate method, total exchangeable bases, with a formula to calculate the lime requirement to the percent saturation desired. He proposed checking this by adding the indicated amount of calcium carbonate, wetting and drying on the steam bath, measuring pH and comparing the result with the pH desired. He considered this more desirable than use of titration curves.

The presence of soluble salts in soils tends to lower the pH and therefore affects the use of pH in estimating the lime requirements of soils. Hester and Shelton (15) attributed seasonal changes in soil pH to changes in salt content. Coleman and Mehlich (8) stated that seasonal changes of salt content could change the pH as much as 0.5 unit. Bell[1] reported an average increase in pH of 0.3 unit in Tennessee soil samples by leaching with water, and he attributed this to removal of soluble salts. Shaw (46) stated that leaching could result in a pH rise of as much as 0.5 to 1.0 unit.

pH may be measured in dilute salt solutions of definite concentrations to eliminate some of these variations. Dunn (11) stated that pH values were 1 to 1.5 units lower in salt solutions than in water.

\1/ Bell, F. F. A lime requirement study of some Tennessee soils. Unpub. M.S. thesis, University of Tennessee, Knoxville, Tenn. 1949.

Dunn (11) and Webster and Harward (59) reported better correlations of pH with base saturation when taken in salt solutions than in water. Schofield and Taylor (43) used 0.01 molar solution of calcium chloride in which to measure pH and to arrive at a constant for each soil which they called the "lime potential." They used the formula: pH - 1/2 pCa = CONSTANT. Coleman and Mehlich (8) considered this a more definite index to soil reaction than pH as it does not vary with salt content or soil-water ratio. Such values, however, must be related to the soil in the field in order to be meaningful for lime requirements. Graham (13) suggested an interpretation of pH_S values of mineral soils measured in 0.01 molar calcium chloride in terms of percent base saturation and crop suitability.

III. EXCHANGE ACIDITY AS AN ESTIMATE OF LIME REQUIREMENT

A great deal of recognition has been given to the determination of exchange acidity as an estimate of lime requirement (33,35,45,46). A clear definition of methods and consideration of other soil properties are considered necessary to understand the use of exchange acidity in making lime recommendations (33,34,35).

The ammonium acetate, $BaCl_2$-triethanolamine (TEA), and neutral calcium acetate methods appear to be of major importance in determination of exchange acidity.

The ammonium acetate method described by Peech, et al (34) involves extraction with neutral normal ammonium acetate for the simultaneous determination of exchangeable bases and cation exchange capacity (33,34,

35,44). Exchange acidity is determined by difference. Peech, et al (34) stated that this method gave high results on soil high in organic matter due to decomposition.

The TEA method as described by Peech, et al (34) involves extraction with barium chloride buffered at pH 8.2 with triethanolamine. Peech (33) and Peech and Bradfield (35) stated that this method gave results comparable to titration with ammonium hydroxide to pH 8.3. Pratt and Holowaychuk (39) compared neutralization curves to pH 7.6 with the TEA method and obtained concordant results for exchange acidity. Several workers have reported lower values with the ammonium acetate method than with TEA on 1:1 clay minerals and organic soils (34,35,39,52). Hanna and Reed (13) had lower results on all soils with ammonium acetate than with the TEA method.

Pratt and Holowaychuk (39) preferred the TEA method over the ammonium acetate method as fulfilling the concept of Bradfield and Allison of a base saturated soil. Mehlich (27) pointed out the more complete neutralization of 1:1 and organic soils by this method as compared to those buffered at a lower pH.

The neutral calcium acetate method proposed by Shaw (46) involves replacement with neutral normal calcium acetate and titration with barium hydroxide to pH 8.8. Shaw (47) preferred this to methods using extracting electrolytes at higher pH's as this method gave results nearer the pH of 6.5 considered as the ideal soil reaction. With this method Shaw and MacIntire (52) obtained results in good agreement with the ammonium acetate method on a number of soils. Their results agreed with the TEA

method on a 2:1 soil, but were lower on 1:1 and organic soils. They concluded that the calcium acetate method was the one best adapted for routine determination of lime requirements to raise pH of soils to near neutrality. Shaw (46) demonstrated in the laboratory that reaction with the amounts of calcium carbonate indicated by the calcium acetate method would bring widely differing soils to near pH 7.0. Shaw (48) brought 12 of 13 differing soils to pH 6.7 to 7.0 by use of this method, but on 2 organic soils he had lower pH values.

Woodruff (61) proposed the paranitrophenol (PNP) buffer method. In this method a buffer solution is used and depression of pH from 7 is attributed to exchange acidity. Shaw and MacIntire (52) found lower results with this method than with several others. This method is rapid and suited to routine laboratory use.

Many other methods for determination of exchange acidity have been described which differ in adaptability for routine laboratory work, and most of them give a range of results on different soils due to the nature of the method and extracting solution (5,6,19,33,35,42,45,49,52).

IV. ALUMINUM TOXICITY

A number of researchers have indicated that the problem in acid soils is toxicity of aluminum or other elements to plants, or have attributed the major beneficial effects of liming to correction of this toxic condition (4,7,10,18,23,35,38,42). Toxic levels of aluminum under certain conditions for certain plants were described by Fiskell and Hutton (12) and Schmehl, et al (40).

V. EXCHANGEABLE CALCIUM AND CALCIUM SATURATION

Exchangeable calcium alone is not a very satisfactory indicator of lime needs or response. Peech and Bradfield (35) stated that exchangeable calcium alone was useful for estimating lime requirement only on soils of very low cation exchange capacity. Lineberry and Burkhart (22) found that percent calcium saturation and total calcium were important on growth and calcium content of strawberries. Schmehl, et al (40) had equal growth of alfalfa on pH 4.8 with 500 lbs calcium as on pH 6.5 and 3800 pounds exchangeable calcium. Mehlich and Colwell (31) and Mehlich and Reed (32) found a lower percent calcium saturation on 1:1 clay soils was as effective as a higher calcium saturation on 2:1 soils. Schmehl, et al (40) stated that low calcium content in plants was due to antagonistic effects of Al, Mn, and H on calcium absorption rather than on low calcium supply. Arnon, et al (2) stated that calcium was not absorbed at pH 4 to 5 but between 5 to 7. Coleman, et al (7) pointed out that the degree of calcium saturation required is related to kind of exchange material and source of charge.

VI. INCUBATION AND EQUILIBRATION METHODS

Incubation and equilibration methods for lime requirement have been described or compared by Shaw (45,49,50), Shaw and MacIntire (52), Bradfield and Allison (5), and Shoemaker and Pratt (54). Such methods are less rapid and more cumbersome than desired for routine laboratory work. They involve consideration of time, temperature, and carbon dioxide variations. In many cases incubations have resulted in higher

results than other methods. Shaw (50) had a greater decomposition of calcium carbonate with incubation than the calcium acetate and TEA lime requirements and less than with calcium hydroxide equilibration. Shoemaker and Pratt (54) obtained higher results with an incubation method than with the Woodruff buffer method.

VII. LIME FACTORS

Laboratory methods are quantitative and are controlled to a certain end point. The difficulty of relating laboratory measurements of lime requirements to a field application and successful adjustment of soil reaction is involved with many factors and has led to acceptance of various lime factors (7,11,33,35,49,56). This is a number by which the lime requirement as determined in the laboratory is multiplied to arrive at a field recommendation of lime. In practice, lime factors of 2 or 3 are used (7).

It appears that a complete understanding of lime requirements of soils will include correlation of laboratory determinations with changes in field pH due to liming. Involved in this understanding will be measurements of changes in soil properties, the field conditions under which they were accomplished, the kind of lime applied, and the depth and manner of its mixing in the soil.

CHAPTER III

MATERIALS AND METHODS

I. SELECTION OF SOILS AND SAMPLING

Soils of the four series selected represent an important range of parent materials and textures found in West Tennessee. The Dundee, Falaya, and Hymon are young, somewhat poorly drained alluvial soils. The Dundee sandy loam soils represent parent material of the Mississippi Delta. They are associated goegraphically with slightly acid to slightly alkaline soils. Underlying the sandy layers of the Dundee at about 18 inches depth is finer-textured, darker-colored, less-acid material. Parent material for the Falaya silt loam soils was washed from loess soils. They are high in silt, and are associated with acid loess soils over a large part of West Tennessee. The Hymon sandy loam soils are associated with shallow loess and Coastal Plains soils and have mixed parent materials but are mainly from Coastal Plain materials. The Grenada silty clay loam soils are moderately well-drained upland soils formed from deep loess and have a pan at about 18 to 24 inches depth. The Grenada sites selected had been severely eroded and had slopes of about 6 to 10 percent gradient. The present surface represents the original B_2 horizon. These sites represent the finer-textured soils of the deep loess area. The Hymon soils are among the coarser-textured soils of West Tennessee. There are both finer and coarser-textured soils than these selected, but they are less extensive and less suitable for agriculture because of some other factors as well as undesirable texture.

The Dundee soils are the least extensive of these four but they are important in association with other soils in an intensively cropped high value land area.

All of the soils selected are suited to several agronomic crops and are found in other states. All are acid and have pale colors or mottling below 18 inches depth.

Samples were taken at 0 to 6 inches depth and 6 to 12 inches with a sampling tube on several sites of each series. From one site of each series a large bulk sample of the 0 to 6 inch layer was collected with a spade for greenhouse work. Sites with a known liming history were avoided, and those sites with high pH values were eliminated. Three sites for each soil were selected making a total of 24 samples representing two layers on three sites of each series. These were air-dried, sieved through a 2 mm. sieve, and stored in cardboard containers.

II. LABORATORY METHODS

The determinations of easily oxidizable organic matter, exchange acidity by the TEA method, and pH except where otherwise specified, were by procedures proposed by Peech, et al (34).

Exchangeable bases were determined on the Beckman Model DU flame photometer after extraction with ammonium acetate according to the method of Shaw and Veal (53). The cation exchange capacity was determined by the distillation method of Peech, et al (34) with the boric acid modification described by Pierce and Haenisch (36). The exchange acidity was then determined by difference between the total exchangeable bases and

cation exchange capacity.

Exchange acidity was determined directly by the calcium acetate method of Shaw (46) and the PNP method of Woodruff (61).

Acid soil was prepared by leaching 300 g. soil with one liter of 0.05N HCl and washing with distilled water and ethyl alcohol.

The calcium hydroxide titration procedure of Dunn (11) was essentially followed by adding increments of calcium hydroxide solution to 25 g. of soil, periodic swirling, and measuring pH after 48 hours.

Exchangeable aluminum was determined by extraction with KCl as described by Coleman, et al (9), but was titrated to pH 8.1 with standard NaOH, using a Beckman pH meter to determine the end-point of the titration.

"Lime Potential" was determined by method of Schofield and Taylor (43). It is recognized that this procedure should include pH measurements more precise than to 0.1 pH which was the case in this work.

III. INCUBATION WITH GROUND LIMESTONE

Fifty-gram soil charges were treated with minus 40 plus 50 and mill-run ground limestone in amounts equal to the exchange acidity as determined by the neutral calcium acetate method. Standard sieves were used to separate the sized fraction. The calcium carbonate equivalents of both limestone materials used were determined by the AOAC method (3). These charges were kept moist by adding distilled water every 48 hours, and were incubated at room temperature. At the end of each of five weeks, one set of treated charges for each soil was dried and stored. On

these the pH was measured and the residual carbonate was determined by the steam distillation method of Shaw and MacIntire (51). The amount of lime which had reacted was determined by subtracting residual carbonate from amount of lime added.

IV. GREENHOUSE EXPERIMENT

The bulk samples were air-dried and sieved. Lime treatments on a basis of calcium carbonate equivalent were mixed with 9-pound charges of the soils. The lime treatments ranged from zero to amounts greater than the exchange acidity as determined by the TEA method for each soil. After mixing, the treated charges were placed in 10-inch diameter pots. The lime used was a minus 40 plus 50 fraction from the same source as that for the incubation phase of this study.

Ladino clover was planted and grown for eleven months in three replications of these treatments. Clover was thinned to 15 plants per pot and grown in the greenhouse until after the third of nine cuttings. Following the third cutting, the pots were placed in an open cold frame outdoors. Pots were watered with tap water every 48 hours. pH was determined on soil samples taken from each pot near the end of the test. Clover was harvested in early bloom stage.

CHAPTER IV

RESULTS AND DISCUSSION

Standard terminology is used wherever possible. It should be emphasized that the textural range of soils represents a large proportion of the acid soils in West Tennessee, and comparisons among them will have a wide application in that area, particularly for those properties directly related to texture. In comparisons between surface and sub-surface layers it should be recognized that three soils are young and alluvial in origin. The other soil, Grenada, although old, is represented here by two layers within the illuvial horizon. For these reasons comparisons between these layers of these series are expected to be less distinct than similar comparisons among ABC horizons of old soils in the same region.

I. pH VALUES OF UNTREATED SOILS

The soils were all acid, ranging from the very strongly acid Grenada soils to the slightly acid or moderately acid Dundee. The Hymon and Falaya soils were somewhat intermediate in pH, but Falaya was more acid and more like Grenada in this respect (see table 1).

The sub-surface layers were not greatly different from the surface layers in pH (see table 2).

pH values among the Grenada soils are more consistent than in the other series. This may be due to more uniformity of parent material and greater age.

Table 1.--Cation exchange capacity, exchangeable bases and exchange acidity values obtained by ammonium acetate extraction and pH of surface layers

Series	Sample No.	Milliequivalents per 100 grams soil						Percent saturation		pH
		Cation exchange capacity	Exchangeable cations			Total bases	Exch. acidity	Base	Calcium	
			Ca	Mg	K					
Dundee	1	8.11	6.25	1.19	0.38	7.82	0.29	96	77	6.0
	3	7.33	5.42	1.23	0.29	6.94	0.39	95	74	6.0
	5	5.07	3.50	0.70	0.36	4.56	0.51	90	69	5.7
Falaya	7	11.62	4.06	2.50	0.21	6.77	4.85	58	35	5.0
	9	11.27	4.42	2.38	0.36	7.16	4.11	63	39	4.7
	11	6.54	3.05	0.90	0.22	4.17	2.37	64	47	5.1
Hymon	13	6.54	2.88	0.82	0.21	3.91	2.63	60	44	5.5
	15	4.51	2.00	0.70	0.27	2.97	1.54	66	44	4.8
	17	4.06	2.75	0.37	0.16	3.28	0.78	81	68	5.5
Grenada	19	12.51	1.72	2.87	0.26	4.85	7.66	39	14	4.5
	21	10.48	2.45	2.05	0.26	4.76	5.72	45	23	4.6
	23	14.54	3.92	3.90	0.31	8.13	6.41	56	27	4.6

Table 2.--Cation exchange capacity, exchangeable bases and exchange acidity values obtained by ammonium acetate extraction and pH of sub-surface layers

Series	Sample No.	Milliequivalents per 100 grams soil						percent saturation		pH
		Cation exchange capacity	Exchangeable Cations			Total Bases	Exch. acidity	Base	Calcium	
			Ca	Mg	K					
Dundee	2	8.68	6.50	0.86	0.34	7.70	0.98	89	75	6.3
	4	6.72	4.06	0.86	0.25	5.17	1.55	77	60	5.9
	6	6.09	4.06	0.74	0.38	5.18	0.91	85	67	5.9
Falaya	8	9.47	3.92	2.26	0.21	6.39	3.08	67	41	5.0
	10	10.71	3.05	1.84	0.20	5.09	5.62	47	28	4.5
	12	6.20	3.00	0.86	0.16	4.02	2.18	65	48	5.0
Hymon	14	4.62	2.00	0.78	0.13	2.91	1.71	63	43	5.5
	16	4.40	1.82	0.74	0.22	2.78	1.62	63	41	5.0
	18	3.83	3.05	0.41	0.21	3.67	0.16	96	80	5.8
Grenada	20	12.28	1.42	2.79	0.22	4.43	7.85	36	12	4.5
	22	10.93	2.45	2.38	0.26	5.09	5.84	47	22	4.4
	24	13.30	3.92	2.87	0.32	7.11	6.19	53	29	4.6

II. EXTRACTION WITH NEUTRAL NORMAL AMMONIUM ACETATE

The Grenada soils were highest in cation exchange capacity, exchange acidity and magnesium, and lowest in base saturation and calcium saturation (see tables 1 and 2). The Hymon soils were low in cation exchange capacity, exchangeable potassium, exchangeable magnesium; and are intermediate in exchange acidity, percent base saturation and calcium saturation. The Dundee soils had a moderate cation exchange capacity, high percent base saturation, high calcium saturation and exchangeable potassium, and very low exchange acidity. The Falaya soils were intermediate between the Hymon and Grenada series. They had a wider range in cation exchange capacity which extended from about equal to Hymon to that of Grenada. The Falaya soils had a moderate cation exchange capacity, low calcium saturation, medium base saturation, and a moderate to high amount of exchange acidity.

Calcium was the most abundant basic cation in all soils except Grenada in which magnesium was about equal to calcium. Exchange acidity was most abundant in only one soil, which was Grenada. Exchange acidity was the least abundant cation component in only one soil--Dundee, and this was only in the surface layers.

Abundance of the cations is shown below:

Dundee	$Ca > Mg > K = H + Al$
Falaya	$Ca = H + Al > Mg > K$
Hymon	$Ca > H + Al > Mg > K$
Grenada	$H + Al > Mg = Ca > K$

It is of interest to note that the Dundee soils with a high degree

of base saturation and calcium saturation of 60 to 77%, and with a low amount of exchange acidity, had a pH in the slightly to moderately acid range. The pH range of this group was 5.7-6.3. Their characteristics should be compared to those of the strongly acid Grenada soils which had a high value for exchange acidity, a sizeable cation exchange capacity, a low degree of base saturation, and a very low degree of calcium saturation. Dundee and Grenada represented extremes between which were Hymon and Falaya. The intermediate position of Falaya between Hymon and Grenada may be an expression of texture and parent material. The exchange acidity of Grenada was larger than the cation exchange capacity of Hymon.

The sub-surface layers were not greatly different from the surface layers. The Dundee soils showed a trend for higher cation exchange capacities and higher pH values in the sub-surface. This may be a transition effect between the surface and the darker-colored, finer-textured material underlying the sandy layers.

III. EASILY OXIDIZABLE ORGANIC MATTER

All of the soils were low in organic matter, only one having more than 1% organic matter, which was a Falaya surface with only 1.09%, as shown in table 3.

The Grenada soils were lowest, which might be expected of the B horizons of an old upland soil compared to alluvial soils.

Two of the Dundee sub-surface layers were higher than the surface layers in organic matter. This may be an influence of, or transition to,

Table 3.--Easily oxidizable organic matter content of surface and sub-surface layers

Series	Sample nos.	Organic matter content	
		Surface	Sub-surface
		%	%
Dundee	1,2	0.58	0.54
	3,4	0.36	0.76
	5,6	0.44	0.67
Falaya	7,8	1.09	0.98
	9,10	0.91	0.80
	11,12	0.76	0.47
Hymon	13,14	0.87	0.76
	15,16	0.62	0.38
	17,18	0.65	0.28
Grenada	19,20	0.36	0.11
	21,22	0.73	0.47
	23,24	0.15	0.09

the underlying layer which is darker in color and finer in texture. In the other three soils the content of organic matter was slightly lower in the sub-surface layers. The differences in organic matter between layers may account in part for the differences in cation exchange capacity between surface and sub-surface layers of the same site.

These contents of organic matter were so low that they cannot contribute greatly to the total cation exchange capacity of the soils. The cation exchange capacity then is largely from the mineral fraction of the soils. This was especially true of the Grenada soils, which had the lowest content of organic matter and the highest capacities. It was less true of the Hymon soils, which had the lowest capacities.

IV. EXCHANGE ACIDITY BY THE $BaCl_2$-TRIETHANOLAMINE METHOD

The Grenada soils had highest values for exchange acidity, cation exchange capacity, and lowest values for base saturation and calcium saturation (see table 4). The Dundee soils were lowest in exchange acidity and highest in calcium and total base saturation. The Hymon soils had the lowest cation exchange capacities and were slightly higher in exchange acidity than the Dundee soils, but lower than the other soils. The Hymon and Falaya soils were similar in calcium saturation and total base saturation, but the Falaya had much higher values for cation exchange capacity and exchange acidity, both of which ranged from that of Hymon to that of Grenada.

A comparison of the extremes of Grenada to Dundee and Hymon should be emphasized. Falaya was somewhat intermediate. Grenada had twice as

Table 4.--Exchange acidity values obtained by the $BaCl_2$-Triethanolamine method and some related properties

Series	Sample No.	Milliequivalents per 100 grams soil				percent saturation			
		Exchange acidity		Cation exchange capacity		Base		Calcium	
		Sur.	Sub-sur.	Sur.	Sub-sur.	Sur.	Sub-sur.	Sur.	Sub-sur.
Dundee	1,2	3.38	1.92	11.20	9.62	70	80	56	68
	3,4	1.58	1.98	8.52	7.15	81	72	64	57
	5,6	2.70	2.66	7.26	7.84	63	66	48	52
Falaya	7,8	7.33	6.31	14.10	12.70	48	50	29	31
	9,10	9.41	8.34	16.57	13.43	43	38	27	23
	11,12	3.37	3.55	7.54	7.57	55	53	40	40
Hymon	13,14	3.19	3.73	7.10	6.64	55	44	41	30
	15,16	3.73	3.90	6.70	6.68	44	42	30	27
	17,18	2.84	2.66	6.12	6.33	54	58	45	48
Grenada	19,20	8.52	8.70	13.37	13.13	36	34	13	11
	21,22	7.99	6.74	12.75	11.83	37	43	19	21
	23,24	9.94	9.58	18.07	16.69	45	43	22	23

much exchange acidity as some of the other soils.

The sub-surface layers differed from the surface layers in exchange acidity only slightly and with no distinct pattern. The cation exchange capacities of the sub-surface layers were slightly lower than of the surface layers, and in most cases this may be due to differences in organic matter content. Sub-surface layers differed from surface layers in calcium and total base saturation but not in a distinct pattern. Layers of the Grenada soils were more alike than layers of the other soils in these properties.

V. EXCHANGE ACIDITY BY THE NEUTRAL NORMAL CALCIUM ACETATE METHOD

The Grenada soils had highest values for exchange acidity, as shown in table 5. Hymon and Dundee were low and very close together. Values for Falaya were intermediate but were more like those of Grenada.

The Grenada soils had twice as much exchange acidity as either Dundee or Hymon. The low amounts of exchange acidity in Dundee were due to a high degree of base saturation, but in the Hymon they were not due to base saturation but more to low cation exchange capacities.

Eight of the soils had lower values for exchange acidity in the sub-surface layers than in the surface. The differences were small, and in only one series was this the case on all three sites. This trend was not distinct nor consistent enough to receive much consideration. It may be due in part to differences in organic matter content.

Table 5.--Exchange acidity values obtained by the neutral calcium acetate method

Series	Sample No.	me. exch. acidity per 100 grams soil	Sample No.	me. exch. acidity per 100 grams soil
Dundee	1	1.56	2	0.92
	3	1.25	4	1.05
	5	1.40	6	1.61
Falaya	7	3.62	8	3.22
	9	4.54	10	5.05
	11	2.68	12	2.35
Hymon	13	1.96	14	1.51
	15	1.71	16	1.56
	17	1.10	18	0.86
Grenada	19	5.23	20	5.33
	21	4.49	22	4.10
	23	4.03	24	5.05

VI. LIME REQUIREMENT BY THE PARANITROPHENOL METHOD

Exchange acidity for the Grenada soils was highest, and for Dundee was lowest. Hymon was very close to Dundee but varied considerably from site to site. Falaya was intermediate and had a range of 0.5 to 3.0 milliequivalents per 100 grams soil (see table 6).

The exchange acidity of Grenada was more than twice that of Dundee or Hymon.

Sub-surface layers did not vary greatly nor consistently from their surface layers. The greatest difference between surface and sub-surface was 1.5 milliequivalents per 100 grams soil.

VII. CALCIUM HYDROXIDE TITRATION

The cation exchange capacities as determined by the amount of base required to bring the pH of the acid soils to 7 indicated that Grenada was high and Hymon was low, as the data presented in table 7 indicates. Dundee and Falaya were intermediate with Falaya being higher with values ranging from Hymon to Grenada. Falaya was least consistent from site to site.

The exchange acidity was determined by the amount of base required to bring the pH from that of the untreated soil up to 7. Grenada was highest, Dundee lowest, Hymon next to Dundee, and Falaya occupying the range from Hymon to Grenada.

The acid soils had pH values below 4, with Grenada being lowest and Hymon being highest (see table 8).

The neutralization curves shown in figures 1-5 indicated

Table 6.--Lime requirement values obtained by the Paranitrophenol method

Series	Surface layers				Sub-surface layers			
	Sample no.	pH 1:2	pH in sol'n	Exchange acidity	Sample no.	pH 1:2	pH in sol'n	Exchange acidity
				me.				me.
Dundee	1	6.0	6.9	1.0	2	6.3	7.0	0.0
	3	5.9	7.0	0.0	4	5.8	7.0	0.0
	5	5.5	7.0	0.5	6	5.7	7.0	0.5
Falaya	7	4.9	6.8	2.5	8	4.9	6.8	2.0
	9	4.6	6.7	3.0	10	4.4	6.6	4.0
	11	4.9	6.8	1.5	12	4.8	6.8	2.0
Hymon	13	5.3	6.8	2.0	14	5.3	7.0	0.5
	15	4.9	7.0	0.5	16	5.1	6.9	1.0
	17	5.6	7.0	0.0	18	5.9	7.0	0.0
Grenada	19	4.6	6.5	5.0	20	4.6	6.5	5.0
	21	4.7	6.6	4.0	22	4.5	6.6	3.5
	23	4.5	6.6	4.0	24	4.5	6.5	5.0

Table 7.--Cation exchange capacity and exchange acidity values of surface layers obtained by calcium hydroxide titration

Series	Sample no.	Cation exchange capacity*		Exchange acidity#	
		pH 7.0	pH 8.2	pH 7.0	pH 8.2
		me.	me.	me.	me.
Dundee	1	8.6	10.5	2.6	4.7
	3	7.1	8.9	1.8	2.7
	5	6.0	7.2	2.0	3.2
Falaya	7	11.8	16.5	5.6	10.6
	9	13.6	18.0	7.0	11.7
	11	6.8	10.5	3.8	7.4
Hymon	13	6.2	8.5	3.1	5.4
	15	5.6	7.7	3.4	5.7
	17	4.5	6.2	2.4	4.4
Grenada	19	14.3	17.6	7.3	10.9
	21	13.0	16.3	7.6	11.2
	23	15.7	19.3	7.0	10.6

*Cation exchange capacity as determined by the me. of calcium hydroxide required to bring the pH of the acid washed soil to the pH indicated.

#Exchange acidity as determined by the me. of calcium hydroxide required to bring the pH of the untreated soil to the pH indicated.

Table 8.--pH after additions of calcium hydroxide solution to base unsaturated surface layers*

$Ca(OH)_2$ added	Soil sample number											
	Dundee soil no.			Falaya soil no.			Hymon soil no.			Grenada soil no.		
	1	3	5	7	9	11	13	15	17	19	21	23
me.	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH
0	3.6	3.6	3.4	3.4	3.6	3.7	3.7	3.8	3.9	3.3	3.6	3.4
1.5	4.0	4.0	4.2	3.9	4.0	4.4	4.7	4.6	5.1	3.6	3.9	3.8
3.0	4.4	4.5	4.9	4.2	4.2	5.0	5.4	5.4	6.1	4.0	4.1	3.9
4.5	5.3	5.3	6.2	4.5	4.4	5.8	6.4	6.4	7.0	4.1	4.4	4.1
6.0	6.0	6.4	7.0	4.9	4.8	6.4	6.9	7.2	7.9	4.3	4.7	4.3
7.5	6.5	7.2	8.5	5.4	5.2	7.5	7.6	8.1	9.1	4.6	5.0	4.5
9.0	7.2	8.3	9.6	6.1	5.6	7.6	8.5	8.8	9.7	4.9	5.6	4.7
10.5	8.2	9.1	10.3	6.5	6.2	8.2	9.2	9.6	10.3	5.3	6.2	5.0
12.0	8.8	9.5	10.6	7.1	6.5	9.0	9.8	9.7	10.6	6.1	6.6	5.6
13.5	9.5	10.0	11.1	7.6	6.9	9.3	10.2	10.5	11.1	6.7	7.2	6.3
15.0	9.8	10.3	11.3	7.9	7.4	9.8	10.7	10.8	11.2	7.2	7.6	6.8
16.5	10.3	10.8	11.5	8.3	7.8	10.2	10.9	11.1	11.3	7.9	8.3	7.2
18.0				8.6	8.2	10.4				8.3	8.7	7.6
19.5				9.4	8.8	10.7				9.2	9.2	8.3
21.0				9.6	9.0	10.9				9.5	9.4	8.8

*A soil to water ratio of 1:4 was used except when additions were greater than 16.5 milliequivalents, in which cases a ratio of 1:8 was used. The latter were compared to a 1:4 ratio using water, and corrections for dilution were made.

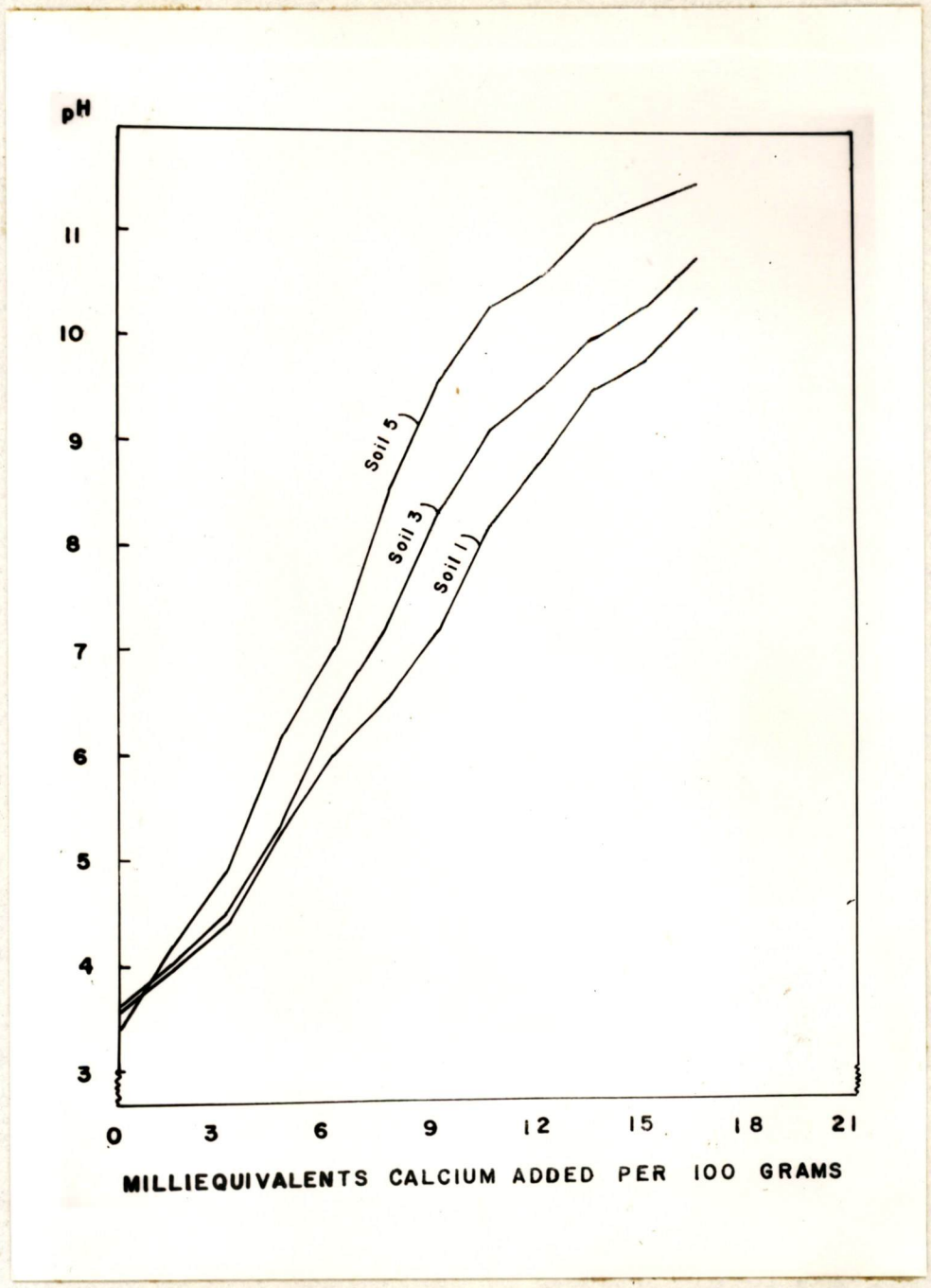


Fig. 1.--Calcium hydroxide neutralization curves, Dundee series.

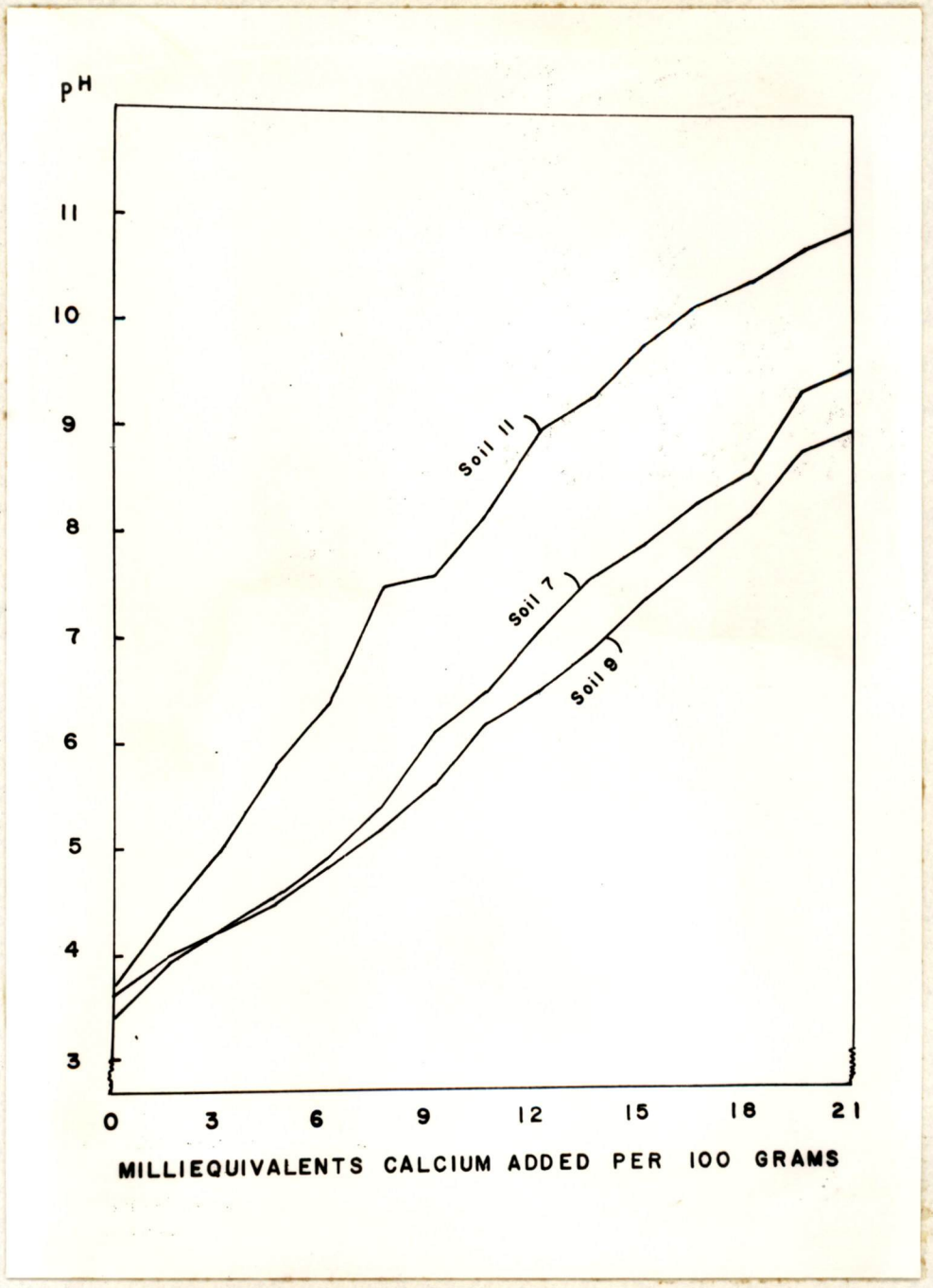


Fig. 2.--Calcium hydroxide neutralization curves, Falaya series.

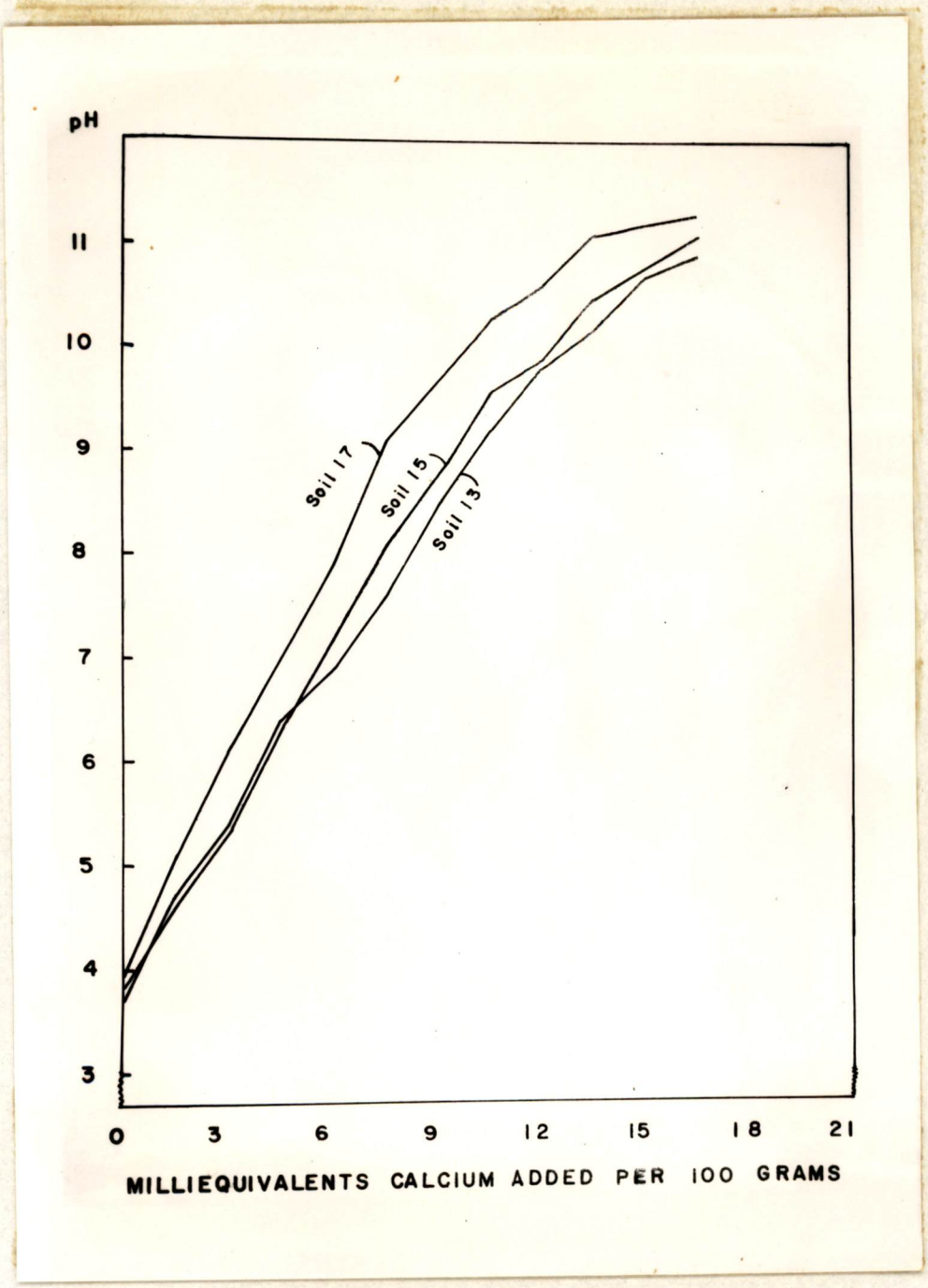


Fig. 3.--Calcium hydroxide neutralization curves, Hymon series.

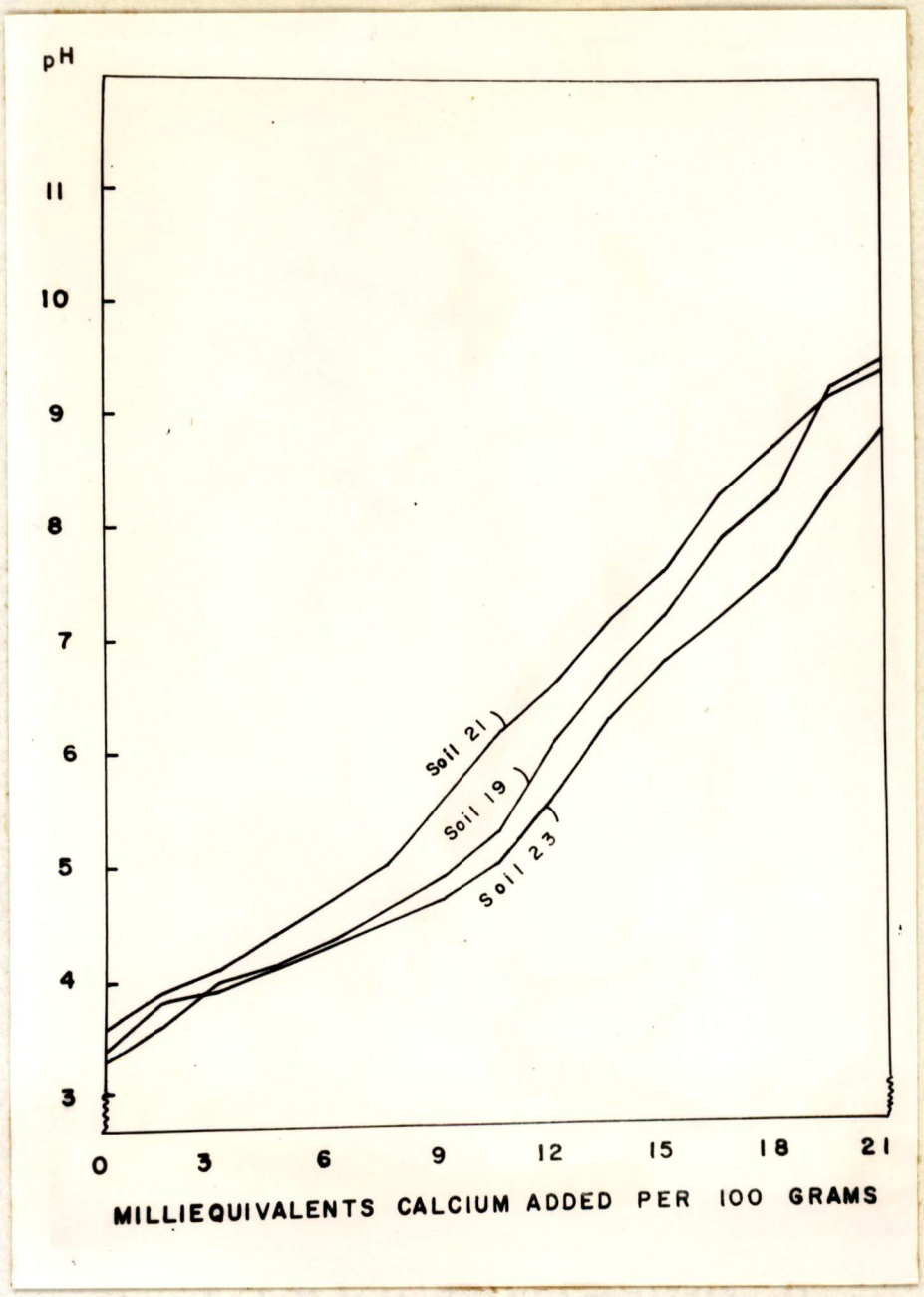


Fig. 4.--Calcium hydroxide neutralization curves, Grenada series.

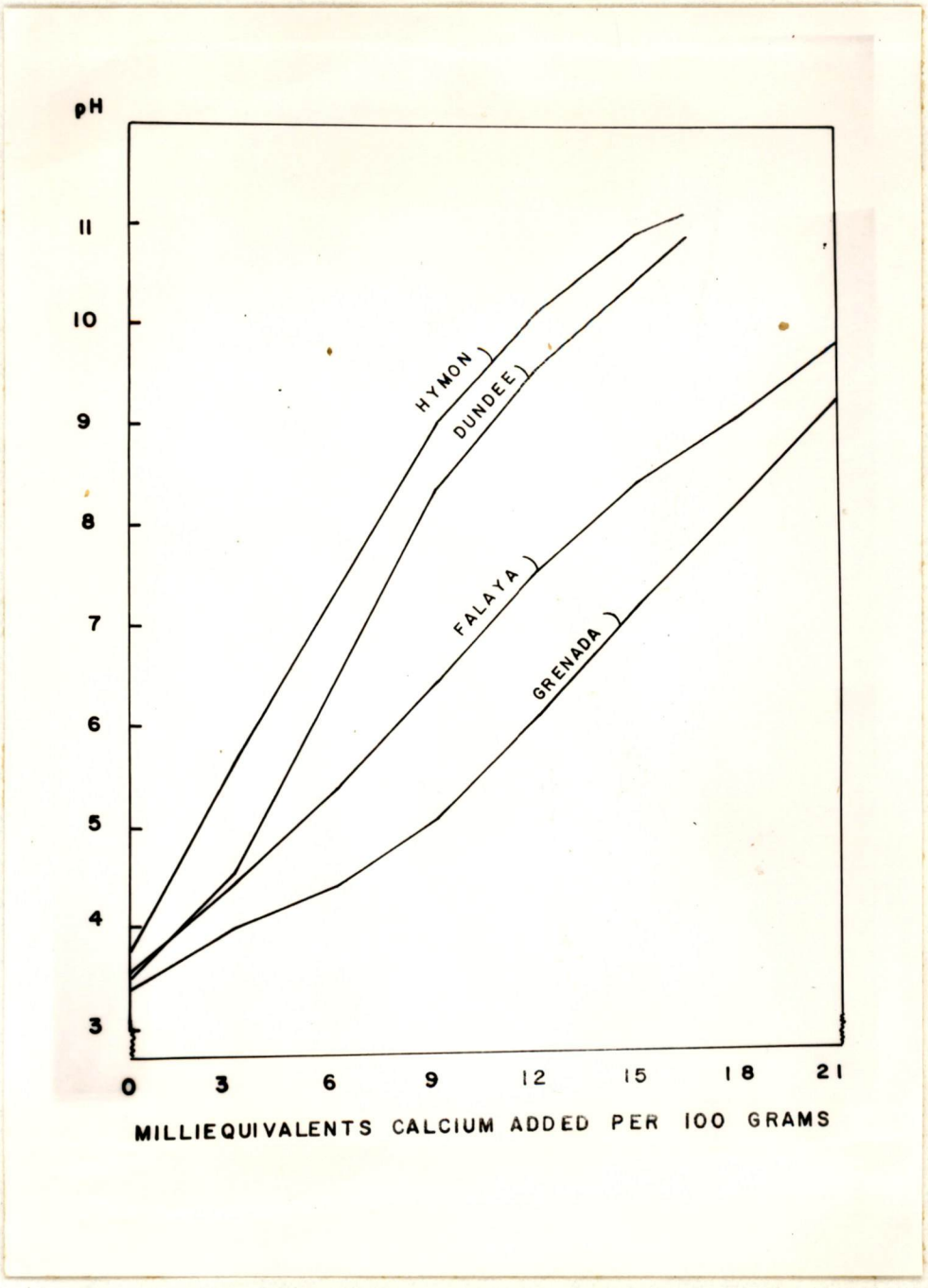


Fig. 5.--Calcium hydroxide neutralization curves, Dundee, Falaya, Hymon, and Grenada series (average of three sites for each series).

considerable differences among the soils. The Hymon soils were low in cation exchange capacity and reached pH 7 with addition of about 5.4 milliequivalents. The curve for these soils was nearly linear with an angle of about 60 degrees up to about pH 9.

The Dundee soils showed some buffering up to pH 4.5, and then the curve assumed an angle of about 60 degrees to about pH 8.4. About 7.2 milliequivalents were required to bring them to pH 7.

The curves for Falaya were nearly linear with an angle of about 45 degrees. About 10.7 milliequivalents brought them to pH 7.

The Grenada soils required 14.3 milliequivalents to reach pH 7 and showed a lag below pH 4.5. Their curve also had an angle of about 45 degrees above pH 4.5.

Buffer curves were prepared using the cation exchange capacity values determined by the ammonium acetate method and the pH values from the calcium hydroxide titration. These are shown in figures 6-10.

The curves for the Dundee soils show an inflection point at 40% base saturation. The major change is between 40 and 60% saturation, and the curve has an angle of about 45 degrees at this point. There is another inflection point at 110 to 120% base saturation.

The Falaya soils have a slight inflection point between 40 and 80% base saturation. One soil has another inflection at about 100% base saturation. The curve for Falaya is almost straight and mainly with an angle of less than 45 degrees. There is a lag between 20 and 40% saturation.

The Hymon curves are nearly straight with the steepest points

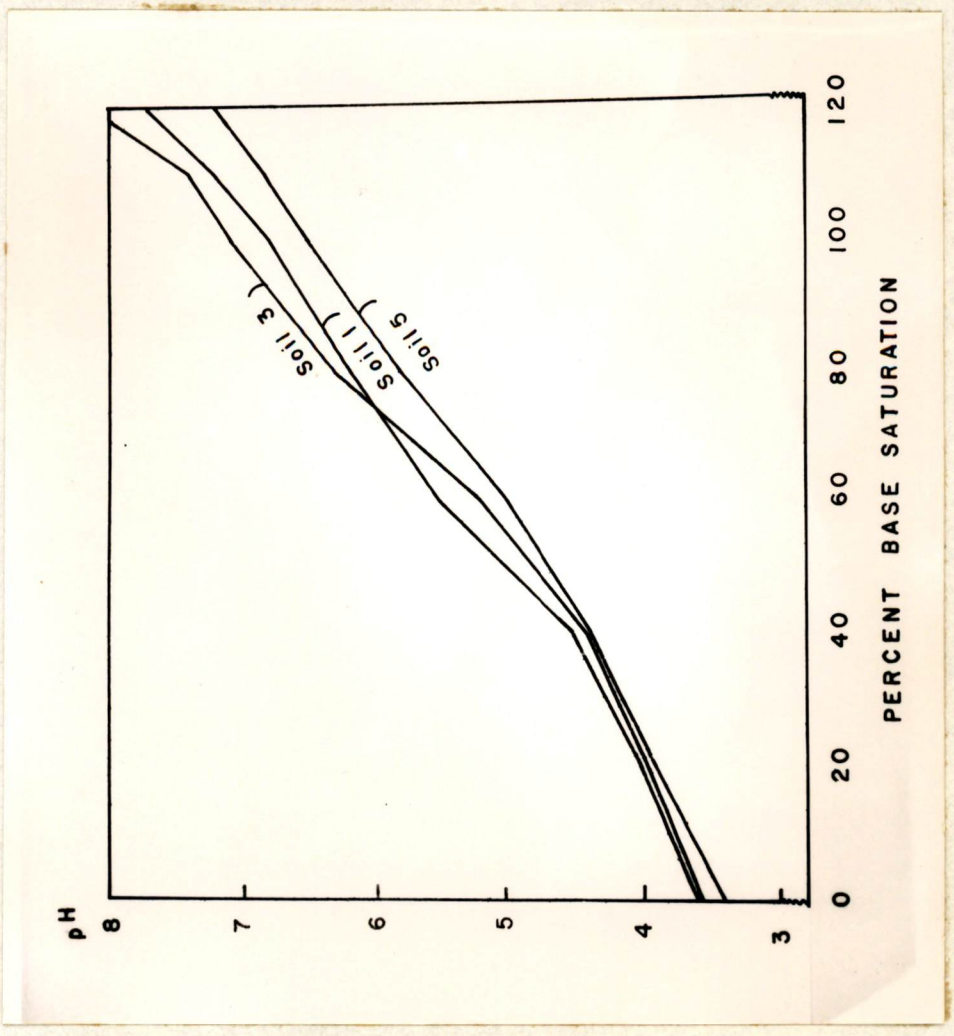


Figure 6.--The pH-percent base saturation relationship in terms of cation exchange capacity determined at pH 7, Dundee series.

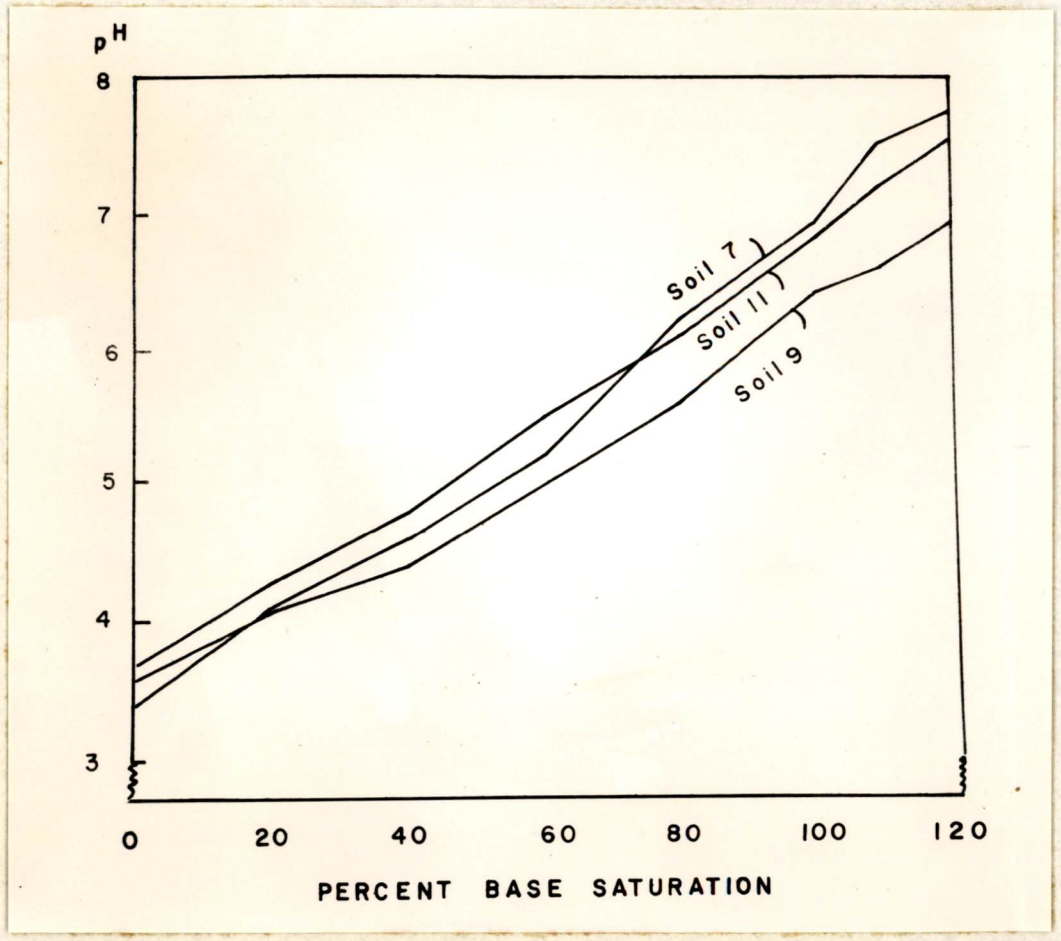


Figure 7.--The pH-percent base saturation relationship in terms of cation exchange capacity determined at pH 7, Falaya series.

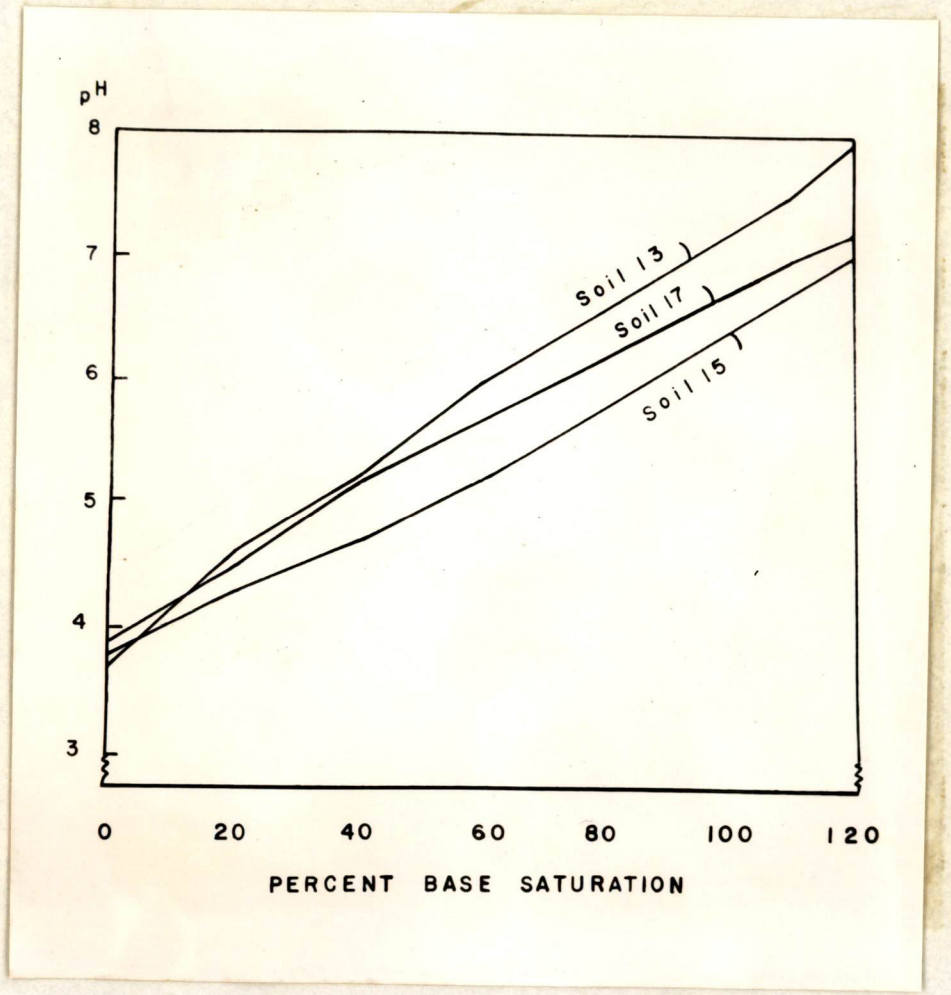


Figure 8.--The pH-percent base saturation relationship in terms of cation exchange capacity determined at pH 7, Hymon series.

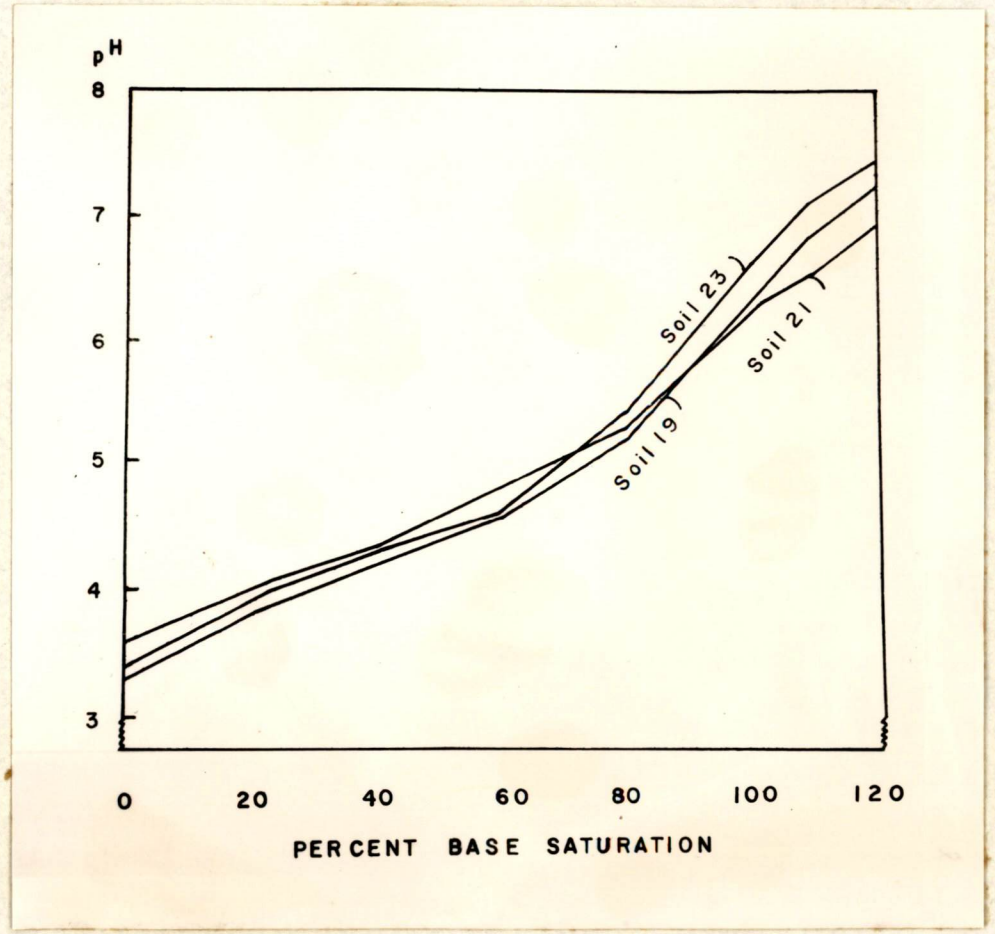


Figure 9.--The pH-percent base saturation relationship in terms of cation exchange capacity determined at pH 7, Grenada series.

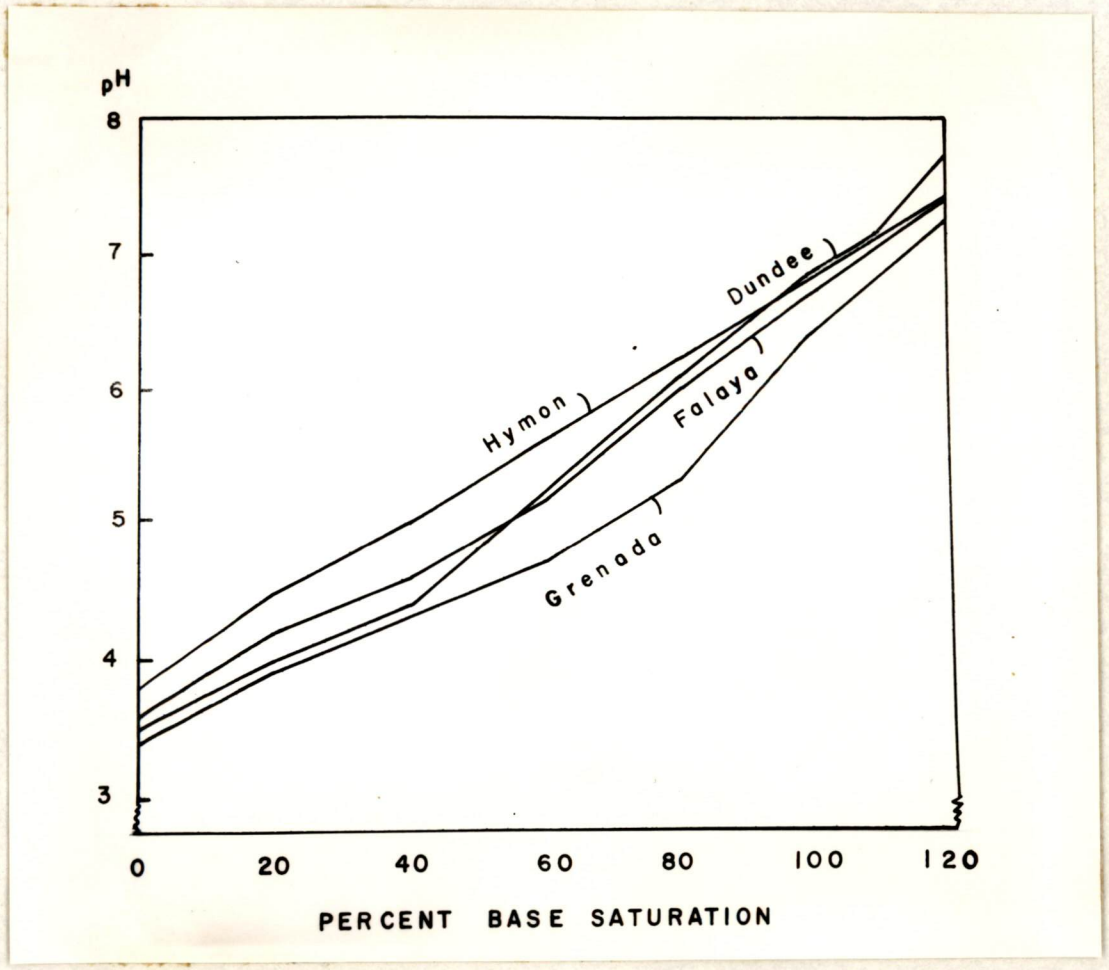


Figure 10.--The pH-percent base saturation relationship in terms of cation exchange capacity determined at pH 7, Dundee, Falaya, Hymon, and Grenada series (average of three sites for each series)

below 60% saturation. The angle is mainly less than 45 degrees.

The Grenada curves show a little inflection between 40 and 60% but there is a definite inflection at 80% saturation to an angle of about 55 degrees. The angle below 60% is about 20 to 30 degrees.

Curves are also shown in which the three sites for each soil are averaged. The Grenada curve has a lower position than the other soils and has a major inflection point at 80% saturation. Hymon has the straightest curve and the least inflection point. Dundee and Falaya show mild inflection points between 20 to 60% saturation, and Dundee shows another at about 110%.

The divergence of the Grenada curve below that of the other soils is at 40 to 100% saturation. Grenada is 0.4 to 0.9 pH unit below Hymon at all degrees of saturation, and 0.7 to 0.9 pH unit lower from 40 to 90%. This can also be related to the larger cation exchange capacity of Grenada. The curve of Grenada resembles the curve of 2:1 clay-type soils; the other 3 soils resemble 1:1 clay-type soils as shown by Coleman and Mehlich (8). Jones and Hoover (21) considered Grenada a 2:1 clay type on a basis of titration curves. Results from clay mineral studies of Grenada soils show that they contain considerable quantities of Montmorillonite and Illite as well as Kaolinite (55).

VIII. INCUBATION OF SOILS WITH GROUND LIMESTONE

Analyses of the limestone materials used are shown in table 9. It is noted that the mill-run material did not meet requirements of the Tennessee state law in that less than 50% passed a 40-mesh screen as

Table 9.--Limestone Analyses

Sieve analysis of mill-run limestone

Size range	Sample number 1	2	3	Ave.
	%	%	%	%
Greater than 10 mesh	5.15	6.11	6.68	5.98
10 to 20	30.69	33.41	33.13	32.41
20 to 40	20.30	18.58	19.70	19.53
40 to 60	12.55	11.99	11.62	12.05
60 to 100	10.52	10.11	10.13	10.25
Finer than 100	20.56	18.86	18.73	19.78*
Sum	99.77	99.06	99.99	100

Less than 10	94%
Less than 40	42%

Calcium carbonate equivalent

	Sample number 1	2	Ave.
	%	%	%
Mill-run	85.53	85.81	85.67
Minus 40 plus 50 mesh	88.06	88.79	88.42

*Includes loss of 0.40

indicated by this unofficial sample and analysis.

The amounts of lime applied were equal to the exchange acidity as determined by the neutral calcium acetate method for each soil. Most of the applied lime reacted, and a considerable part of the reaction took place in the first week, with a range of 31 to 100% as shown in table 10. A range of 81 to 100% of the lime had reacted by the end of the fifth week with an average of over 90% for each series. Within sites, however, the results do not show an even trend for amount reacted at weekly intervals. The comparison between the first and fifth weeks is much more consistent.

pH measurements of the soils after incubation with both materials are shown in table 11, and curves showing the reaction progress for each series are shown in figures 11 and 12. Most of the change took place in the first three weeks with the minus 40 plus 50 mesh fraction. Palaya soils had a large increase the first week to pH 5.9, then rose evenly and gradually to pH 6.6. The Grenada soils had an even, moderately low rate of pH change and resulted in the lowest average pH of 6.1.

Results with the mill-run lime were more varied than with the finer-sized fraction, and gave lower pH values. The change was somewhat slower with pH values at four weeks comparing well to those at three weeks with the finer material. The general curve for each soil was somewhat similar to that for the finer fraction except that Grenada showed a large increase in the fourth week. This may indicate the time required for decomposition of the larger lime particles. The dip in pH curves for the third week is not explained. It did not occur for the finer-sized

Table 10.--Amount of lime reacted and percent base saturation of surface soils after incubation with minus 40 plus 50 mesh limestone

Series	Sample no.	Milliequivalents per 100 grams soil						percent reacted		percent base sat.
		Amount added*	amount reacted weeks					1 wk	5 wks	5 wks
			1	2	3	4	5			
Dundee	1	1.56	1.16	1.56	1.46	1.56	1.56	74	100	116
	3	1.25	1.10	0.95	1.25	0.65	1.25	88	100	112
	5	1.40	0.43	0.53	0.93	1.06	1.13	31	81	112
Falaya	7	3.62	3.02	2.72	2.72	2.12	3.42	83	94	88
	9	4.54	3.04	4.24	2.84	2.94	4.52	67	100	104
	11	2.68	1.18	1.03	2.23	1.83	2.53	44	87	99
Hymon	13	1.96	1.96	1.96	1.16	1.16	1.76	100	90	87
	15	1.71	0.96	1.11	1.31	1.31	1.71	56	100	104
	17	1.10	1.10	0.90	0.90	1.00	1.10	100	100	108
Grenada	19	5.23	4.65	4.80	4.90	5.00	4.80	89	92	77
	21	4.49	2.86	3.26	4.16	3.26	4.16	64	93	85
	23	4.03	3.45	3.50	3.70	4.00	3.80	86	94	82

*Equal to the exchange acidity as determined by the neutral calcium acetate method.

Table 11.--pH values of surface layers after incubation with limestome

Series	Sample no.	No tmt.	Minus 40 plus 50 mesh					Mill-run ground limestome				
			weeks					weeks				
			1	2	3	4	5	1	2	3	4	5
		pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH
Dundee	1	6.0	6.1	6.6	6.8	6.7	6.9	6.1	6.7	6.4	6.9	6.7
	3	6.1	6.2	6.6	6.7	6.8	6.9	6.2	6.5	6.6	6.8	6.9
	5	6.0	6.1	6.5	6.6	6.5	6.8	6.3	6.2	6.3	6.6	6.6
Falaya	7	5.2	5.8	6.0	6.1	6.4	6.7	5.8	6.1	5.7	6.1	6.4
	9	4.7	5.6	6.0	6.2	6.5	6.4	5.5	5.6	5.6	6.0	6.4
	11	4.6	6.2	6.4	6.6	6.6	6.7	6.1	6.3	6.2	6.7	6.5
Hymon	13	5.6	5.9	6.1	6.4	6.3	6.7	5.8	6.1	6.0	6.5	6.6
	15	5.3	5.9	6.1	6.4	6.7	6.5	5.8	6.0	5.8	6.3	6.6
	17	5.9	6.5	6.8	7.0	7.0	7.1	6.5	6.7	6.8	7.0	7.2
Grenada	19	4.8	5.3	5.6	5.8	5.9	6.1	4.9	4.8	5.1	5.9	5.9
	21	4.9	5.5	5.7	5.9	6.0	6.3	5.0	5.3	5.2	5.5	5.9
	23	4.6	5.2	5.4	5.6	5.8	6.0	4.8	5.0	4.9	5.7	5.9

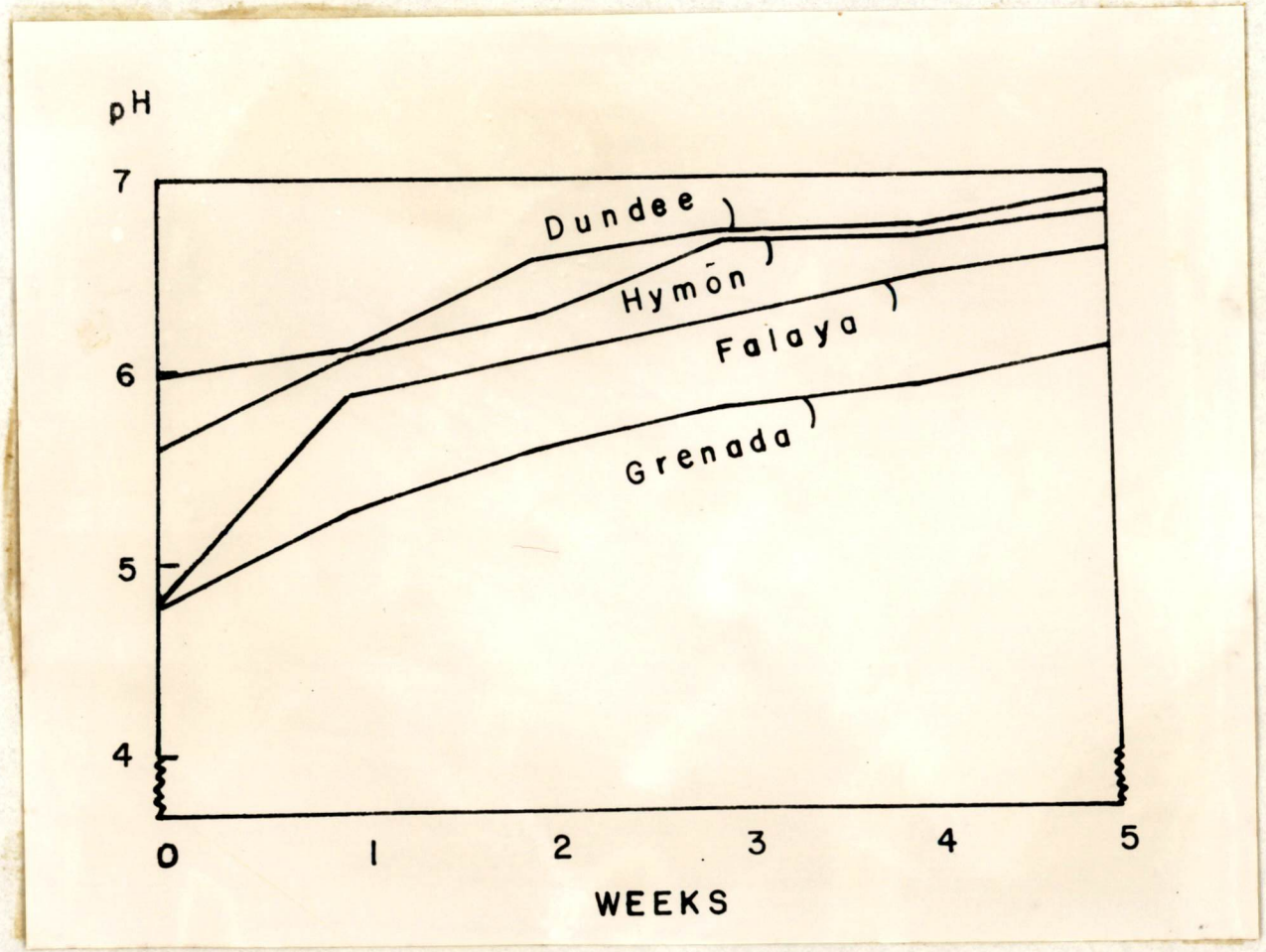


Figure 11.--Change in pH of soils limed with minus 40 plus 50 mesh limestone incubated at room temperature for five weeks (average of three sites for each series)

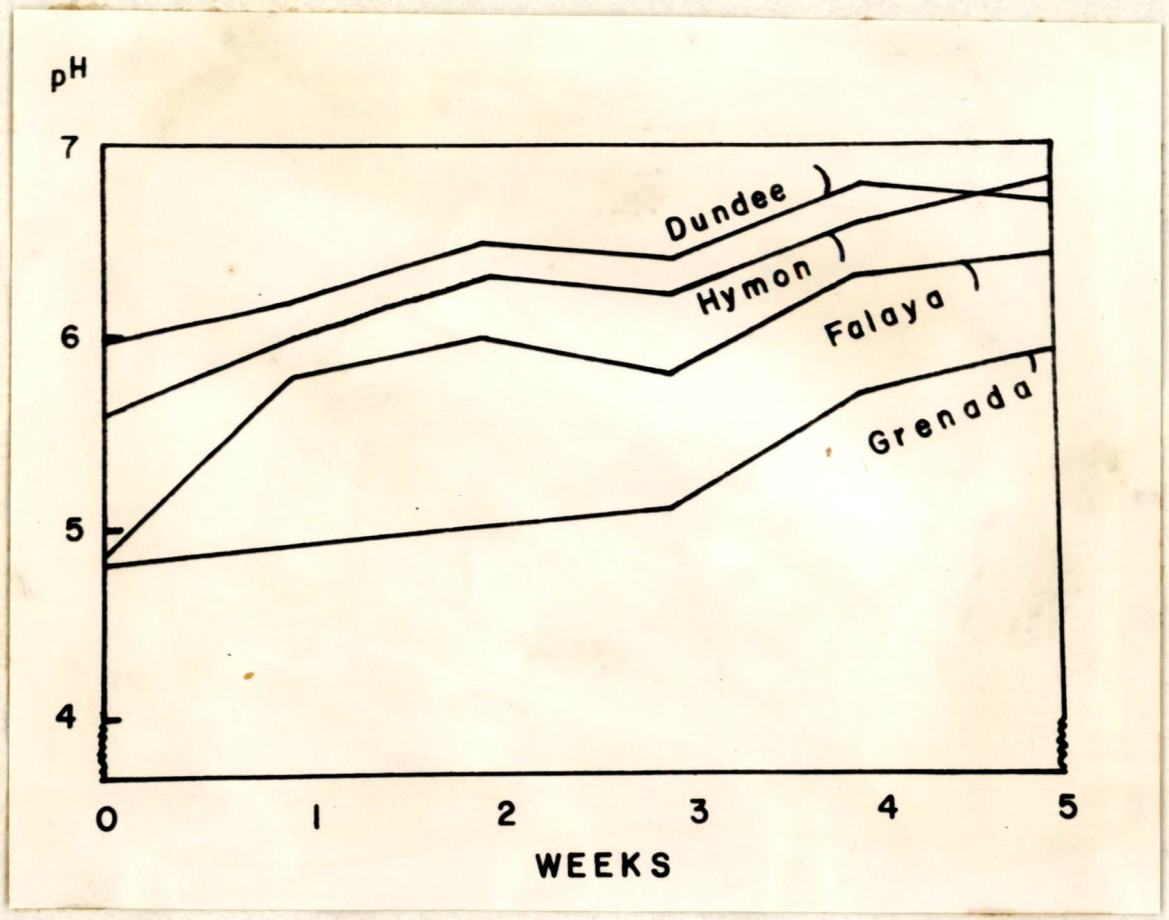


Figure 12.--Change in pH of soils limed with mill-run ground limestone incubated at room temperature for five weeks (average of three sites for each series)

treatments handled similarly. The early increase of Falaya is noted with both materials, and is fairly consistent among the three sites.

Difference in pH values and shape of curves between the two liming materials do not appear to be inconsistent with differences in particle size and calcium carbonate equivalent.

The percent base saturation indicated by the pH values at five weeks are shown in table 10. Average percent base saturation for each series was: Dundee 94, Falaya 94, Hymon 97, and Grenada 93.

Application of the amounts of lime indicated by this method resulted in relatively satisfactory pH adjustment to pH 6.4 to 7.2 for all soils except Grenada, which had a range of 5.9 to 6.3. pH values for each surface soil at the end of each week are shown in table 11. Average pH values for the series 5 weeks after liming with the finer material were: Dundee 6.9, Falaya 6.6, Hymon 6.8, and Grenada 6.1.

Since the amount of lime unreacted in the Grenada series was less than 10% of the addition and less than 4% of the cation exchange capacities, a complete reaction would not have accomplished change to pH 7. The pH range reached by Grenada was above the inflection point at 80% of saturation where rapid change is expected.

On a basis of these data, the calcium acetate method appears to be well suited for use in making liming recommendations. However, the adjustment was not as satisfactory for the more strongly buffered Grenada soils.

IX. EXCHANGE ACIDITY BY POTASSIUM CHLORIDE EXTRACTION

Results of this determination and related properties are shown in tables 12 and 13. Permanent charge exchange capacity is the sum of the exchangeable bases and exchangeable aluminum. The pH dependent charge is the difference between the permanent charge exchange capacity and the TEA cation exchange capacity.

The Grenada soils were high in exchangeable aluminum, aluminum saturation, permanent charge cation exchange capacity, and pH dependent charge, and lowest in percent base saturation of permanent charge cation exchange capacity.

The Dundee soils were lowest in exchangeable aluminum and percent aluminum saturation. They were intermediate in permanent charge exchange capacity, low in pH dependent charge, and very high in base saturation of permanent charge exchange capacity.

The Falaya soils were intermediate in exchangeable aluminum and low in aluminum saturation; they were intermediate in permanent charge exchange capacity, high in pH dependent charge, and high in percent base saturation of permanent charge exchange capacity.

The Hymon soils were low in exchangeable aluminum and aluminum saturation, permanent charge exchange capacity, and pH dependent charge, and were high in base saturation of permanent charge exchange capacity.

Falaya had the highest ratio of pH dependent charge to permanent charge of the surface layers. Dundee had the lowest ratio, and Grenada and Hymon were intermediate. Grenada soils were more consistent, which may be due to uniformity of parent material and age. The higher amounts

Table 12.--Exchangeable aluminum values obtained by potassium chloride extraction and related comparisons of surface layers

Series	Sample No.	pH in 1 N KCl	Milliequivalents per 100 grams soil: Exch. Al	Exch. bases (pH 7)	Perm. charge ex.cap.*	pH dep. charge#	TEA exch. cap.	Ratio of pH dep.ch. to perm. charge	Percent of perm. charge exch. cap.: Base sat.	Al sat.	Lbs.exch. Al per acre
Dundee	1	5.2	0.13	7.82	7.95	3.25	11.20	0.41	98	2	23
	3	5.9	0.06	6.94	7.00	1.52	8.52	0.22	99	1	11
	5	5.1	0.20	4.56	4.76	2.50	7.26	0.53	96	4	36
Falaya	7	4.7	0.52	6.77	7.29	6.81	14.10	0.93	93	7	94
	9	4.4	1.01	7.16	8.17	8.40	16.57	1.03	88	12	182
	11	4.8	0.37	4.17	4.54	3.00	7.54	0.66	92	8	67
Hymon	13	4.9	0.25	3.91	4.16	2.94	7.10	0.71	94	6	45
	15	4.7	0.34	2.97	3.31	3.39	6.70	1.02	90	10	61
	17	5.4	0.17	3.28	3.45	2.67	6.12	0.77	95	5	31
Grenada	19	4.2	3.22	4.85	8.07	5.30	13.37	0.66	60	40	580
	21	4.2	2.06	4.76	6.82	5.93	12.75	0.87	70	30	371
	23	4.3	1.98	8.13	10.11	7.96	18.07	0.79	80	20	356

*Permanent charge exchange capacity is the sum of the exchangeable bases and exchangeable aluminum.

#pH dependent charge is the TEA exchange capacity minus the permanent charge exchange capacity.

Table 13.--Exchangeable aluminum values obtained by potassium chloride extraction and related comparisons of sub-surface soils

Series	Sample no.	pH in 1 N KCl	Milliequivalents per 100 grams soil					Ratio of pH dep.ch. to perm. charge	Percent of perm. charge exch. cap.		Lbs.exch. Al per acre
			Exch. Al	Exch. bases (pH 7)	Perm. charge ex.cap.*	pH dep. charge#	TEA exch. cap.		Base sat.	Al sat.	
Dundee	2	5.5	0.06	7.70	7.76	1.86	9.62	0.24	99	1	11
	4	5.4	0.13	5.17	5.30	1.85	7.15	0.35	98	2	23
	6	5.2	0.13	5.18	5.31	2.53	7.84	0.48	98	2	23
Falaya	8	4.6	0.56	6.39	6.95	5.75	12.70	0.83	92	8	101
	10	4.2	1.60	5.09	6.69	6.74	13.43	1.01	76	24	288
	12	4.6	0.51	4.02	4.53	3.04	7.57	0.67	89	11	92
Hymon	14	5.0	0.29	2.91	3.20	3.44	6.64	1.07	91	9	52
	16	4.7	0.39	2.78	3.17	3.51	6.68	1.11	88	12	70
	18	5.4	0.13	3.67	3.80	2.53	6.33	0.67	97	3	23
Grenada	20	4.2	3.52	4.43	7.95	5.18	13.13	0.65	56	44	634
	22	4.3	1.91	5.09	7.00	4.83	11.83	0.69	73	27	344
	24	4.1	2.86	7.11	9.97	6.72	16.69	0.67	71	29	515

*Permanent charge exchange capacity is the sum of the exchangeable bases and exchangeable aluminum.

#pH dependent charge is the TEA exchange capacity minus the permanent charge exchange capacity.

of pH dependent charge in Grenada and Falaya may be due in part to higher clay content.

Falaya and Grenada were quite similar in amount of exchangeable bases and pH dependent charges except for soils 11 and 12. Falaya had a higher ratio of pH dependent charge to permanent charge exchange capacity. This difference was not great and resulted from the greater amount of exchangeable aluminum in Grenada which contributed to its larger permanent charge exchange capacity. This difference may indicate a difference in type of clay mineral in the two soils. If the larger clay content of Grenada were the same type as in Falaya, it seems that these ratios of the two soils would be more nearly alike.

On a basis of permanent charge cation exchange capacity, all the soils were comparatively well saturated with bases except Grenada, which was 60 to 80% saturated. Dundee was very highly saturated. Grenada and Dundee represent extremes in amount of exchangeable aluminum, aluminum saturation, and degree of base saturation. Hymon and Falaya were intermediate in these properties, but Falaya was more like Grenada. Grenada alone showed much aluminum saturation or amount of exchangeable aluminum.

The sub-surface layers of Falaya and Grenada were higher in exchangeable aluminum and aluminum saturation than their surface layers with the exception of soil 21. They had slightly lower ratios than their surface soils. Hymon had a slightly higher ratio in the sub-surface. The layers otherwise were rather similar on all sites.

Permanent charge cation exchange capacities of these soils were lower than cation exchange capacities determined by other methods as

"exchangeable hydrogen" was not included.

pH values in salt solution before titration are lower in all cases than pH in water and support the other comparisons among soils described above. Maximum reduction in pH was 0.8 unit, and the average was 0.39 unit for all soils.

X. CLAY MINERAL TYPE AS INDICATED BY OTHER PROPERTIES

The Dundee, Falaya, and Hymon soils appear to contain mainly 1:1 clay mineral types based on buffer curve, pH dependent charge, exchangeable aluminum, and aluminum saturation.

The Grenada soils may have both 1:1 and 2:1 clay mineral types. The pH dependent charges indicate presence of a 1:1 type. The amount of exchangeable aluminum and degree aluminum saturation indicate a 2:1 clay type. The type of buffer curve also indicates presence of a 2:1 clay type. A mixture of both types appears to be the most likely possibility. Jones and Hoover (21) considered the predominant clay mineral in a Grenada soil to be a 2:1 type. This was found to be the case in data reported in Southern Co-operative Series Bulletin 61 (55).

XI. COMPARISON OF THE SOILS ON A BASIS OF THE AMOUNT OF BASE REQUIRED TO BRING ABOUT ONE pH UNIT CHANGE

One concept of lime requirement is the amount of lime required to raise the soil pH one unit. Table 14 provides a comparison of this kind expressed in milliequivalents per 100 grams of soil. The two columns from the calcium hydroxide titration provide a numerical comparison of

Table 14.--Lime requirement as determined by the number of milliequivalents of base per 100 grams soil required to bring about one pH unit change

Series	Sample No.	By Calcium Hydroxide Titrat. Untreated soil to pH 7	Acid soil to pH 7	With ground limestone Untreated soil to pH reached in 5 wks. of incubation
Dundee	1	2.60	2.53	1.73
	3	1.76	2.09	1.56
	5	1.56	1.67	1.75
	Ave.	1.97	2.10	1.68
Palaya	7	2.79	3.28	2.41
	9	3.06	4.00	2.67
	11	1.99	2.06	1.28
	Ave.	2.61	3.11	2.12
Hymon	13	2.09	1.88	1.78
	15	1.56	1.75	1.42
	17	1.57	1.45	0.92
	Ave.	1.74	1.69	1.37
Grenada	19	2.90	3.86	4.02
	21	3.15	3.82	3.21
	23	2.91	4.36	2.88
	Ave.	2.99	4.01	3.37

the slope for the upper part of the neutralization curves to the whole curve. The Hymon soils and one Dundee soil had a more nearly equal value indicating the upper and lower parts of the curve were not greatly different. The other soils had a larger value for the whole curve which indicates that the lower part of the curve was different and more strongly buffered than the upper part.

On a basis of this kind of comparison, the soils have lime requirements approximately as follows: Grenada 3-4; Falaya 2.6-3.1; Dundee about 2; and Hymon about 1.7.

The soils rank in the same order in a comparison of similar values determined from their reaction with ground limestone. To obtain the values in table 14 it was necessary to extend the curve to pH 7.

The comparison for the titration to the reaction with limestone may be made between the values for the lime requirement determined on the untreated soil. Except for the Grenada soil, lower results were obtained from the incubation method than from the titration.

On these bases the two sandy soils were below 2, the other soils were above 2, and the highest requirement (Grenada) was about double that of the lowest (Hymon).

XII. LIME POTENTIAL BY METHOD OF SCHOFIELD AND TAYLOR

The constants for Grenada are lowest and most consistent, as shown in table 15. Those for Dundee are highest and are fairly consistent. Hymon and Falaya are not greatly different, but Falaya is lower. The constants provide a comparison among the soils in similar order to the

Table 15.--Determination of lime potential by method of Schofield and Taylor

Series	Sample No.	In 0.01 Molar calcium chloride solution		pH in water	Reduction of pH in salt solution from pH in water
		pH	pH minus 1/2 pCa		
Dundee	1	5.4	4.26	6.0	0.6
	2	5.7	4.56	6.3	0.6
	3	5.4	4.26	6.0	0.4
	4	5.4	4.26	5.9	0.5
	5	4.9	3.76	5.7	0.8
	6	4.9	3.76	5.9	1.0
Falaya	7	4.7	3.56	5.0	0.3
	8	4.6	3.46	5.0	0.4
	9	4.4	3.26	4.7	0.3
	10	4.3	3.16	4.5	0.2
	11	4.7	3.56	5.1	0.4
	12	4.6	3.46	5.0	0.4
Hymon	13	4.9	3.76	5.5	0.6
	14	5.0	3.86	5.5	0.5
	15	4.8	3.66	4.8	0.0
	16	4.7	3.56	5.0	0.3
	17	5.6	4.46	5.5	+ 0.1
	18	5.8	4.66	5.8	0.0
Grenada	19	4.2	3.06	4.5	0.3
	20	4.2	3.06	4.5	0.3
	21	4.2	3.06	4.6	0.4
	22	4.3	3.16	4.4	0.1
	23	4.4	3.26	4.6	0.2
	24	4.3	3.16	4.6	0.3

other determinations. They are somewhat in proportion to pH values of the base unsaturated surface soils. These pH values and the percent base saturation (pH 7) for Hymon and Grenada are in agreement with the scale Graham proposed (13); Dundee and Falaya are not.

The pH values in calcium chloride solution were lower in all cases but two than in water. Maximum reduction was on pH unit, and the average was 0.37 unit. The greatest reduction was in Dundee. These reductions agree very well with the range for Missouri soils reported by Graham (13). Hymon and Grenada soils appear high in salt content; Dundee is low. The salt content of Hymon soils was quite varied, while that of Falaya was intermediate and relatively consistent.

The pH values in 1 N potassium chloride solution shown in tables 12 and 13 agree very well with those in the calcium chloride solution, and provide a similar comparison among the soils.

XIII. RESULTS OF GREENHOUSE EXPERIMENT

Ladino clover was planted in December and thinned to 15 plants per pot. Nine cuttings were made between the following March and November. After the third cutting the pots were put in an open cold frame outdoors. Pots were watered with tap water every 48 hours. Samples were obtained at the end of the test, and pH data on these samples are shown in table 14. The data for yield of clover were analyzed for each soil on a cutting basis, and also by periods consisting of three cuttings each. These data are presented in tables 14 and 15 and are discussed by soils.

The data in table 16 is presented primarily to indicate presence

Table 16.--Yields obtained from clover grown on limed soils in greenhouse experiment

Milliequivalents added*, pH# and yield of clover+ resulting, and base saturation' approximated

Dundee:	me.	0	1	2	3	4			
Sample 5	pH	5.23	5.60	5.73	5.90	6.00			
	Yield	13.8	12.1	12.6	14.1	13.1ø			
% base sat.		66	75	78	84	86			
Falaya:	me.	0	1	2	3	4	6		
Sample 11	pH	5.40	6.20	6.60	6.77	6.87	7.20		
	Yield	12.6	12.8	13.3	14.8	13.9	16.6	LSD .05	1.9
								LSD .01	2.5
% base sat.		58	83	94	100	103	110		
Hymon:	me.	0	1	2	3	4			
Sample 17	pH	5.47	6.00	6.53	6.77	6.90			
	Yield	11.3	11.1	11.0	11.5	11.3ø			
% base sat.		52	72	92	102	107			
Grenada:	me.	0	2	4	6	8	10	12	
Sample 23	pH	4.90	5.13	6.17	6.40	6.67	6.87	7.07	
	Yield	12.9	12.7	12.1	13.3	13.9	12.2	13.5ø	
% base sat.		68	73	93	97	101	106	110	

*Milliequivalents added per 100 grams soil at beginning of test.

#pH values are averages of three pots at end of test.

+Yield is grams dry weight (air dry) on a per pot basis, three replications and nine cuttings.

'Percent base saturation was obtained by comparing the pH values obtained to the calcium hydroxide titration curve for that soil.

øYields were not significantly different at P = 0.05.

Table 17.--Yields obtained from clover grown on Falaya silt loam (soil 11) in greenhouse experiment

A. By cuttings

Average air-dry weight in grams per pot (three replications)

Cutting Number	me. lime added per 100 grams soil					
	0	1	2	3	4	6
1	10.6	11.3	11.0	12.2	11.1	12.3
2	6.6	7.4	7.8	8.7	6.9	7.2
3	15.0	16.9	18.6	17.5	18.1	17.7
4	23.0	19.3	19.5	22.3	21.6	27.1
5	19.4	18.5	20.5	21.4	20.6	24.1
6	14.1	14.9	15.3	14.9	16.3	17.1
7	5.9	8.8	8.6	8.3	9.7	10.7
8	9.0	8.2	9.7	15.7	10.3	17.3
9	10.0	10.1	8.4	12.6	12.7	16.4
LSD 5%	4.2					
LSD 1%	5.6					
Average all cuts	12.6	12.8	13.3	14.8	13.9	16.6
LSD 5%	1.9					
LSD 1%	2.5					

B. By periods (three cuttings each)

Period	me.	0	1	2	3	4	6
1		32.1	35.5	37.4	38.3	34.1	37.1
2		56.4	52.7	55.4	58.6	58.5	68.3
3		24.9	27.1	26.6	36.5	32.7	44.4
LSD 5%		10.7					
LSD 1%		14.4					
Average all periods		37.83	38.47	39.81	44.47	41.77	49.93
LSD 5%		6.2					
LSD 1%		8.3					

Table 18.--pH of soils used in greenhouse experiment before and after leaching with water

Series	Sample No.	pH		pH units change from leaching
		unleached	leached	
Dundee	5	5.4	5.9	0.5
Falaya	11	4.9	5.6	0.7
Hymon	17	5.9	6.5	0.6
Grenada	23	4.6	4.9	0.3

of soluble salts and their effects on pH of these four soils. It is recognized that these pH values do not entirely agree with others obtained on the same soils.

The pH of each sample was higher after leaching, indicating removal of soluble salts. An average increase of 0.52 unit was obtained by leaching.

Clover yields on this experiment are shown in detail only on Falaya. Response on other soils was not obtained.

Dundee

Leaching has apparently resulted as the unlimed soil has a lower pH than before the trial. It is assumed that the watering schedule was excessive. Yields were not significantly affected by treatment on this soil which had a pH of 5.7, base saturation of 90%, calcium saturation of 69%, and 2.7 me. of exchange acidity by the TEA method. There was a pH rise with increasing lime treatments. The data do not permit other inferences about lime response due to the effects of leaching.

Falaya

The increase in pH (unlimed treatment as compared to the soil before treatment) may be due to removal of soluble salts. Differences in yields were significant, especially at the highest lime rate of 6 me. and in the later cuttings. The highest rate resulted in a pH of 7.20, corresponding to a base saturation of 110%, and in the highest yield, which was significantly different from the check at the 1% level. Response was indicated in the first period and in the eighth cutting,

beginning with the 3 me. treatment, which resulted in a pH 6.77 corresponding to about 98% base saturation. A pH raise of .3 unit was noted per me.

For this soil the greatest yield response was obtained with a treatment higher than any of the laboratory methods indicated except one, the calcium hydroxide titration to pH 8.2. A response was obtained from treatments as indicated by the TEA method and the calcium hydroxide titration to pH 7. Amounts indicated by the PNP and calcium acetate methods resulted in a response but not highest yields. The calcium hydroxide titration to pH 8.2 and all estimates by use of pH were higher than the highest treatment. Lime factors would have been required with all methods by calcium hydroxide titration to pH 8.2 to estimate enough lime for the highest yield.

It should be noted that the clover responded to a higher pH than 7, and to a higher base saturation than 100% in this case.

Hymon

Since the pH of the unlimed soil was very near that of the soil before treatment, it appears that either soluble salts were not present and leaching did not occur, or that such effects about balanced each other. According to Graham's scale (13) and the results shown in table 18, some soluble salts were present in this soil.

Since the 4 me. treatment did not raise the pH above 7.1, perhaps some leaching did occur. No response of clover was obtained in this soil which had a cation exchange capacity of 4.06 and a base saturation of 81% before treatment. The 4 me. treatment resulted in pH values of 6.6-7.1,

and is a higher treatment than most of the laboratory methods indicated for this soil.

A pH increase of 0.36 unit per me. of lime addition was obtained.

Grenada

A pH rise of 0.3 unit in the unlimed soil as compared to the soil before treatment may indicate removal of soluble salts from the unlimed treatment. No significant response was obtained in clover yields, either by cuttings or periods. Seedling grow-off was slower in some of the pots of the 10 and 12 me. treatments, and an analysis was made of treatments 0 to 8 me. without determining a significant difference in yields. The pH rise was rather consistent and in proportion to the rates of application except for an inflection between 2 and 4 me. treatments. The 12 me. treatment resulted in a pH of 7.07, corresponding to a base saturation of 110%. The smallest addition of lime resulting in a pH indicating a base saturation of 100% was the 8 me. treatment (pH 6.67 and 101% base saturation). The TEA, calcium hydroxide titration to pH 8.2, and the pH methods would have indicated using this much lime. The ammonium acetate method and titration to pH 7 would have indicated nearly this much, and the PNP and calcium acetate methods were lower.

A pH increase of 0.18 unit per me. lime addition was obtained.

In summary, these data show that the higher treatments used increased the pH values to 6.9 to 7.2 except for Dundee, which is presumed to be leached. These neutralization patterns are similar to those obtained in the titration curves for the same soils. The amount of lime required to reach pH 7 is considerably more than that indicated by most

of the methods used, unless some lime factor is applied. Titration to pH 8.2 appears to be the best method from this set of data. The calcium acetate method did not indicate enough lime for these soils as shown by the data, but the amounts suggested were large enough to bring Falaya and Grenada to 90% saturation.

Explanation for the lack of response of the Dundee and Hymon soils may be that these coarse-textured soils are very high in base saturation of permanent charge, 96 and 95% respectively, and are low in exchangeable aluminum and have calcium saturation at pH 7 of 69 and 68% respectively. Another possibility is that of excessive watering of Dundee (removals).

It is possible that the watering schedule resulted in a too wet condition of Grenada for clover growth.

XIV. COMPARISON OF METHODS

To compare the methods for determining lime requirement, reference may be made to tables 19 and 20. Three columns were inserted to represent the kind of estimates that might be made from pH alone or by consideration of pH and texture. In the latter case, one-half as much is estimated for sandy soils as for loams and finer-textured soils. It should be realized that these approaches involve lime factors of about 2. The other methods do not include lime factors in the estimates presented. For field use they would require factors and different ones for different situations.

There are considerable differences among methods based on these results. These differences are chiefly in agreement with the nature of

Table 19.--Comparison of lime requirement of surface layers by several methods to pH 7, or as indicated, in tons per acre*

Series	Sample no.	By pH in water#	By pH and texture+	By pH in salt solution#	Amm. acet.	TEA	PNP	Ca. acet.	Exch. acid.	$Ca(OH)_2$ titration to pH 7	$Ca(OH)_2$ titration to pH 8.2	Incub.'
Dundee	1	2.0	1.0	3.2	0.2	1.7	0.5	0.8	0.1	1.3	2.4	0.9
	3	2.0	1.0	3.2	0.2	0.8	0.0	0.7	0.1	0.9	1.4	0.7
	5	2.6	1.2	4.2	0.3	1.4	0.3	0.7	0.1	1.1	1.7	0.9
Falaya	7	4.0	4.4	4.6	2.5	3.7	1.3	1.9	0.3	2.8	5.3	2.2
	9	4.6	4.6	5.2	2.1	4.8	1.5	2.3	0.6	3.6	5.9	3.1
	11	3.8	3.8	4.6	1.2	1.7	1.3	1.4	0.2	1.9	3.7	1.6
Hymon	13	3.0	1.5	4.2	1.4	1.6	1.0	1.0	0.2	1.6	2.8	1.3
	15	4.4	2.2	4.4	0.8	1.9	0.3	0.9	0.2	1.8	2.9	1.2
	17	3.0	1.5	2.8	0.4	1.5	0.0	0.6	0.1	1.2	2.2	0.6
Grenada	19	5.0	5.0	5.6	3.9	4.3	2.5	2.7	1.7	3.7	5.5	4.5
	21	4.8	4.8	5.5	2.9	4.0	2.0	2.3	1.1	3.9	5.6	3.4
	23	4.8	4.8	5.2	3.2	5.0	2.0	2.1	1.0	3.5	5.3	3.5

*Estimates are made to the next largest tenth of a ton.
#Using rule of thumb: 2 tons lime per acre per pH unit raise desired for all soils.
+Using rule of thumb: 2 tons lime per acre per pH unit raise desired for loams and finer-textured soils and 1/2 this rate for sandy loams.
'Calculated to pH 7 assuming same rate of change to pH 7 as that which actually occurred to a lower pH.

Table 20.--Comparison of lime requirement of sub-surface layers by several methods to pH 7, or as indicated, in tons per acre*

Series	Sample no.	By pH in water#	By pH and texture+	By pH in salt solution#	Amm. acet.	TEA	PNP	Ca. acet.	Exch. acid.
Dundee	2	1.4	0.7	2.6	0.5	1.0	0.0	0.5	0.1
	4	2.2	1.1	3.2	0.8	1.0	0.0	0.6	0.1
	6	2.2	1.1	4.2	0.5	1.4	0.5	0.9	0.1
Falaya	8	4.0	4.0	4.8	1.6	3.2	1.0	1.7	0.3
	10	5.0	5.0	5.4	2.8	4.2	2.0	2.6	0.8
	12	4.0	4.0	4.9	1.1	1.8	1.0	1.2	0.3
Hymon	14	3.0	1.5	4.0	0.9	1.9	0.3	0.8	0.2
	16	4.0	2.0	4.6	0.8	2.0	0.5	0.8	0.2
	18	2.4	1.2	2.5	0.1	1.4	0.0	0.5	0.1
Grenada	20	5.0	5.0	5.6	4.0	4.4	2.5	2.7	1.8
	22	5.2	5.2	5.4	3.0	3.4	1.8	2.1	1.0
	24	4.8	4.8	5.4	3.1	4.8	2.5	2.6	1.5

*Estimates are made to the next largest tenth of a ton.
#Using rule of thumb: 2 tons lime per acre per pH unit raise desired for all soils.
+Using rule of thumb: 2 tons lime per acre per pH unit raise desired for loams and finer-textured soils and 1/2 this rate for sandy loams.

differences described by other workers in the review of literature. These differences are especially related to differences in pH of extracting solution or of the end-point selected for each procedure.

Estimates by use of exchange acidity method are lower than by other methods. The adjustment involved in this case might be with respect to pH 6. These estimates appear to be low.

Differences among these soils are such that the use of pH alone would not be a very satisfactory method of determining the lime needs of all of them. Consideration of texture with pH improves the comparison to the other methods over use of pH alone. Although use of pH in salt solutions with the same "rule of thumb" used with pH in water resulted in higher estimates, it did not compensate for soil differences.

Results obtained for estimating the amount of lime required are in proportion to the pH of the extractant or the end-point of titration.

A relationship exists among values for the calcium acetate method, calcium hydroxide titration to pH 7, and incubation which tends to support the use of the calcium acetate method. It is interesting to note the increasing amount of lime required as either volume of soil or length of time of contact is increased. This is supported to some extent by the pH values developed in the greenhouse work in which the amount of soil and time of contact were both the greatest. These observations tend to support the use of lime factors for determining the total amount of lime to apply in the field. The calcium acetate method seems to be very workable for all the soils but Grenada, for which it gave somewhat low results. The TEA method seems to fit the Grenada soils very well.

Results with the TEA method and titration to pH 8.2 gave highest results for exchange acidity on all soils. The PNP method gave low results. The neutral calcium acetate method gave results in agreement with the ammonium acetate method on Falaya and Hymon, lower on Grenada, and slightly higher on Dundee.

The calcium hydroxide titration to pH 7 gave higher results than the ammonium acetate procedure; gave good agreement with TEA on Dundee and Hymon, the sandy soils, but was lower on Falaya and Grenada which are finer textured. The calcium hydroxide titration to pH 8.2 was somewhat higher than TEA for all soils. Pratt and Holowaychuk (39) had concordant values for a titration to pH 7.6 and results with the TEA method.

Incubation with ground limestome gave some higher results than the calcium acetate method on Dundee, Falaya, and Hymon, and considerably higher on Grenada. With few exceptions incubation gave good agreement with the titration to pH 7. Incubation results were lower than the TEA values except on Grenada where these methods were in near agreement.

The estimates for lime from pH in salt solution are very close to those for titration to pH 8.2 on Grenada, in fair agreement for Falaya, but are higher on Hymon and Dundee.

The values for the TEA method compare to those for pH in water and pH and texture, especially the latter.

In establishing a "rule of thumb" for making lime recommendations from pH measurements, it should be as reasonable to estimate higher factors for fine-textured soils as it is to use lower factors for coarser soils than silt loams. If amounts for Grenada as a silty clay loam were

revised upward in these estimates, they would correspond better to the values obtained by incubation, recognizing that no lime factor was used in the latter.

There is a better degree of agreement among methods on the Dundee and Hymon soils than on the others. This may be due to these coarser-textured soils having lower lime requirements and not being strongly buffered.

Comparisons of methods among the sub-surface layers are not different from those for the surface layers.

CHAPTER V

SUMMARY AND CONCLUSIONS

Lime requirements of 0-6 inch and 6-12 inch layers from three sites of the Dundee, Falaya, Hymon, and Grenada series by the neutral normal ammonium acetate, TEA, PNP, and neutral calcium acetate methods were determined. pH in water and 0.01 Molar calcium chloride, easily oxidizable organic matter, and exchange acidity were also determined on both layers. Cation exchange capacities, exchangeable bases, and exchangeable aluminum were determined. A calcium hydroxide titration was run on the surface layers. Surface layers were limed with two limestone materials in amounts equal to the calcium acetate exchange acidity and incubated at room temperature for five weeks. pH and residual carbonate were determined at weekly intervals. Limestone materials used were analyzed.

Soil from one site of each series was limed with a range of rates of a minus 40 plus 50 mesh limestone and placed in 10 inch pots in the greenhouse. Ladino clover was planted and grown eleven months and harvested nine times. pH of the soil in each pot was measured at the end of the experiment.

pH of untreated soils used in the greenhouse was taken before and after leaching with water.

From these studies the following general conclusions may be drawn:

1. The cation exchange capacities of these soils by all methods used fit the pattern Grenada, Falaya, Dundee, and Hymon from high to low.

The Falaya soils had the widest range and the older Grenada soils were the most consistent.

2. On a basis of pH dependent charge, Grenada and Falaya were about equal with Hymon next and Dundee lowest.

3. All soils were low in organic matter content, only one exceeding 1%.

4. Calcium was the most abundant cation in all series except Grenada, in which acidity exceeded calcium. Grenada was the only series with appreciable amounts of exchangeable aluminum, and had the highest percentage aluminum saturation.

5. On a basis of exchange acidity, the soils consistently rank from high to low--Grenada, Falaya, Hymon, and Dundee.

6. On a basis of the amount of base required to raise the pH one unit, the soils rank from high to low--Grenada, Falaya, Dundee, and Hymon. The two sandy soils are more alike and the two soils formed from loess are more alike in this respect.

7. Differences among results with methods are closely related to differences in the pH of extractant and pH of the end-point. The PNP method gave low results, and the TEA method gave high results in nearly all cases.

8. The Dundee soils have a medium cation exchange capacity, are well saturated with bases, and are weakly buffered. They have some similarities to the Hymon soils in neutralization characteristics, although they have a higher cation exchange capacity and greater degree of base saturation.

9. Grenada, Falaya, and Hymon exhibit a distinct textural comparison. The sandy Hymon has a low cation exchange capacity, is weakly buffered, and has low values for exchangeable aluminum. The silty clay loam Grenada has a high cation exchange capacity, high values for exchangeable aluminum and exchange acidity, low degree of base saturation, and is strongly buffered. The silt loam Falaya is intermediate and occupies the range between these two in many respects, but is more like Grenada. A similar relationship is shown in lime potential for these soils.

10. The Grenada soil contains both 2:1 and 1:1 clay mineral types; properties of the other series are more like those of soils having mainly 1:1 clay mineral types.

11. The sub-surface layers are much like the surface layers on each site. Some differences were observed, but the data do not permit making very great distinctions between properties of these layers. It is not implied that such distinctions do not exist between layers at these depths of other series or of other types and phases of these series.

12. pH alone is not a satisfactory basis for making liming recommendations as evidenced by differences among soils. pH in salt solutions is not a satisfactory basis alone.

13. Where pH is used for the sole basis for making liming recommendations, a consideration of texture would be an improvement, especially among soils of similar parent material.

14. Higher rates of lime than presently recommended should be used on some soils. For silt loams, three tons per acre per pH unit change may be required.

15. An investigation of lime factors should be made, considering field adjustments of pH with known amounts of lime and time.

16. For research laboratory use, the calcium acetate method of Shaw should be given emphasis. The Grenada and related soils should be studied further to determine if this method is as equally applicable to them as to other soils. This method might also be employed in the State soil testing laboratory for a limited number or proportion of samples. On most soils, this method with an appropriate lime factor should give satisfactory results.

17. Field research work on lime should include a correlation of laboratory determinations with crop response, study of those factors affecting lime factors, consideration of the degree of base saturation required by plants on different soils, and relationships of aluminum to soil acidity and plant growth. An investigation of type of clay minerals in soils should be included in the studies.

18. A broad study of the lime requirements of the soils of the State as follows would be beneficial:

a. Determine pH and calcium acetate lime requirement on samples of many sites of soils of the State.

b. Incubate soils with ground limestone equal to the requirement indicated and determine pH. If pH 7 is not reached, incubate again with calculated amount of lime required based on first incubation.

c. From these data, calculate lime required to raise the pH one unit for each soil.

d. Classify the soils into lime requirement groups by soil type or texture, and use these classes for making lime recommendations from pH measurements.

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