APPROVAL SHEET

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ABSTRACT

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Title of Thesis: A Liming Study on Nine Prominent Maryland Soils.

Thesis directed by Dr. J. H. Axley

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A liming investigation was conducted on nine representative soils of Maryland. The importance of liming practices to agriculture were discussed along with a brief historical review of liming investigations. The need for a comparative lime study as a reference for making lime recommendations for Maryland soils was pointed out.

Field experiments were set up on Mattapex silt loam, Matawan sandy loam, Sassafras silt loam, Monmouth loamy sand, Glenelg loam, Chester silt loam, Duffield silt loam, and Emory silt loam soils. These soils were investigated over a three year period to determine the influence of chemically equivalent amounts of coarse, medium and fine grades of limestone, as well as burnt lime and hydrated lime. Each of these five liming materials was applied at two widely different rates. The effects of these various liming treatments on crop response, soil pH values, and exchangeable cations were examined by means of field plot technique and laboratory analyses.

It was reported from the soil pH investigations that all liming treatments employed increased the soil pH above the pH value of the untreated soils. However, the differences within the various liming treatments were not shown to be very great. The hydrated form of lime was shown to give the greatest effect on the soil pH value.

The different grades of fineness of limestone in the heavier application rates used in this investigation did not give significant differences to soil pH. It was concluded that an increase in the quantity of liming material added to the soil produced a larger increase in soil pH. The greatest change in soil reaction was shown to occur within the first two to four months after the liming treatment.

The data, concerning the influence of liming upon the exchangeable cations, indicated that liming resulted in a decrease of exchangeable hydrogen in the soils treated with both light and heavy applications of lime when compared with the untreated soils. It was estimated that approximately two milliequivalents of the liming materials used were required to replace one milliequivalent of exchangeable hydrogen for the acid soils studied. Soils treated with heavy applications of lime showed a significant increase in exchangeable calcium above the values of the untreated soils. The data, as analyzed for all the soil types, showed no significant change in exchangeable potassium, magnesium, or manganese with the liming treatments employed.

The results indicated that there was no general decrease in the ability of any of the lime forms to persist in the soil over the three year period.

The hay yields of this experiment were generally increased by liming. The heavier rate of application did not give as great a hay response as the lighter application. This experiment showed no trend toward increased yields of corn or wheat.

A direct relationship between the pH and percentage hydrogen-saturation was shown to exist for a large group of Maryland soils. By use of this pH and percentage hydrogen-saturation relationship, a rapid and an improved method of estimating the lime needs of Maryland soils was proposed.

A LIMING STUDY ON NINE PROMINENT MARYLAND SOILS

By

John Harry Hoyert, Jr.

Thesis submitted to the Faculty of the Graduate School
of the University of Maryland in partial
fulfillment of the requirements for the
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INTRODUCTION

Lime is at present and has been in the past one of the most important soil amendments. Its use was recorded as one of the earliest agricultural practices. In ancient times it was noted that an application of liming material to certain soils increased the crop yields. It is now known that lime benefits the soil not only by correcting acidity but also by supplying the major nutrient elements of calcium and magnesium, and improving the soil's physical condition. It brings about more favorable conditions for soil micro-organisms and generally promotes optimum conditions of certain essential elements for plant growth. The present importance of liming is shown by the consumption of 29,462,200 tons (35) in the United States during 1946. Maryland alone used 280,000 tons (12) of liming materials in 1948.

In the United States, lime investigations were among the first agricultural experiments recorded. The first experiments on lime in Maryland were made in 1889 at the Maryland Agricultural Experiment Station. The work of Veitch (61) in 1889 upon the lime requirements of soils was accepted as a classic of the time. However, no truly comparative liming studies have been carried out on the various prominent soils throughout Maryland.

Despite the abundance of world-wide lime investigations, the functions and reactions of lime in a soil are not too well understood. The soils of the United States vary considerably in origin, texture, profile development, crop adaptations and use. These differences have brought about varying concepts regarding the uses of liming materials. Furthermore, the results of liming studies in one state may or may not be applicable to the soils of another state. This is due to soil and environmental differences between the various states. These differences, coupled with the controversial nature of many of the liming effects, have indicated the need for further liming studies in Maryland.

The Maryland soil testing laboratory made approximately 6,500 analyses for the farmers of the state in 1949. Future prospects are for an even greater demand for this service. In nearly all cases the farmer wants the testing laboratory to recommend the amount of lime material to apply to his soil. This has led to a definite need for an improved, rapid procedure for lime recommendations.

It has been estimated on the basis of past experience that lime consumption in Maryland should be approximately doubled. In order to increase the consumption of liming materials it is necessary to further show the farmer the benefits of liming. If a more efficient system of liming Maryland soils can be found, the farmer will be more easily convinced of its true value. This research project was designed to investigate liming on some of the prominent soils of the state and to serve as a reference for Maryland agricultural workers in recommending liming practices.

REVIEW OF THE LITERATURE

Historical

Edmund Ruffin (47), a practical farmer of Virginia, was apparently the first American to report on lime usage. This farmer conducted some practical field experiments with lime and wrote an essay on calcareous manures in 1852. Wheeler (65) usually receives credit for the sustained appreciation of the value and need for lime in this country. The Maryland Agricultural Experiment Station published work by Patterson (39) on the occurrence and composition of lime in Maryland in 1900. Later, Patterson (40) showed the use of lime to be economically feasible to the farmer. The problem of lime loss from the soil was investigated by Broughton (7). This worker found that the losses of various forms of lime through drainage were in the following order: gypsum, magnesia lime, and calcium lime. Broughton, Williams, and Frazer (8) studied the effects of different grades of fineness of ground limestone. The use of lime for tobacco crops was examined by Garner and Brown (14). McCall (32) made a study of different forms of lime. He ranked pulverized limestone over pulverized oyster shell and burnt lime in increasing the yield of alfalfa on the eastern shore of Maryland. Probably the outstanding contribution of the time in understanding soil acidity and liming was by Truog (60). The relative value of different forms and degrees of fineness of liming material on soil improvement was studied by White and Gardner (66), and later by Fieger (13) in 1924. Many other important contributions to early liming knowledge were made in studies of crop responses to lime. Some of these were made by Joffe (20) and Hutcheson and Wolfe (19). The dangers of overliming due to the nonavailability of certain essential minor elements has been stressed by Peech (41). Naftel (36) and Parks (38) have shown from field and laboratory results that an overliming injury can result from a boron deficiency.

Influence of Liming on pH

The bulk of research in lime problems has revolved about studies of the hydrogen-ion concentration. Spurway (54) compiled a convenient chart relating the optimum pH values of the soil for specific plants. This work included the majority of our important agricultural crops. One of the earliest studies of hydrogen-ion concentration was by Fieger (13). This worker concluded that, with no exceptions, all of the limestone applications increased the pH value of each soil tested. From his liming experiment he also generalized that soil pH decreased regularly with the depth of the soil sampled. Further, Fieger stated that the finer the state of division of the material added to the test plots the greater was its effect on the hydrogen-ion concentration. Barnes (3) from his work in Ohio concluded that the heaviest textured soil showed less change in pH value per unit of liming material than did the soils of a lighter texture. A more inclusive problem was undertaken by Brown and Munsell (9) who made extensive observations of the lime effect upon soils sampled at many regular depths. They also investigated effects of various methods of incorporating lime with the soil. Lyon (25) studied the relative effectiveness of different grades of fineness in raising the soil of pH value. He concluded that the rate at which limestone increased soil pH was dependent on its degree of fineness. Similar results were obtained by White and Gardner (66), Walker and Brown (63), Pierre (45), and Williams (64). Workers in other states have initiated similar research projects studying the effects of liming materials on the pH values of their particular soils. Schollenberger (48) in Ohio showed that finer ground limestone gave a greater pH effect than the coarser material. Stevenson

(56) in Iowa concluded that the lime requirement of a soils was not increased by organic treatments. Blair (4) and also Joffe (21) studied the relation of pH to lime requirement for New Jersey soils. The former workers concluded from their work that lime requirement could be predicted directly from pH values while the latter scientist disagreed with this conclusion.

<u>Relation of Base Saturation to pH</u>

Pierre and Scarseth (46) studied the percentage base saturation of soil in relation to pH values. They showed that in many soils of the same pH value had the same percentage base saturation of the exchange complex. These workers also concluded that soils of different mineral composition with the same pH value could vary considerably in their percentage base saturation. This relationship between pH value and percentage of base saturation is further substantiated by Merkle (34), Mehlich (33), Peech (41), and Peech and Bradfield (43).

<u>Influence of Lime on Exchangeable Cations</u>

There are many references in the literature concerning the effect of lime on the exchangeable cations of a soil. There is little agreement upon the effect of liming materials on exchangeable potassium. Gilligan (16) concluded that liming increased the replaceable potassium by reducing leaching losses. Abel and Magistad (1) also claimed that liming increased replaceable potassium, but that the improved crop yield removed more potassium from the limed soils. These views are opposed by Snider (53) who reported lower replaceable potassium on heavier limed soils than on highly limed soils. Brewer and Rankin (6) concurred with the findings of Snider. On the other hand, York and Rogers (67) concluded that the addition of lime to a soil could result in an increase or a decrease in available potassium depending on the ability of the soil to fix applied potassium and on the kind, amount, and solubility of potassium-bearing minerals in the particular soil. Other work concerning the influence of liming materials upon the availability of potassium has been contributed by MacIntire and his co-workers (26), (27), (28), (29) who concluded that lime exerted a repressive effect on the solubility of soil potassium. According to Volk (62) liming led to the combination of potassium into the insoluble potassium alumina silicate. Peech and Bradfield (42) thought lime might decrease the availability of soil potassium by initiating the process of transformation of exchangeable potassium to the nonexchangeable forms.

Dion and Mann (11) and also Mann and Quastel (30) have advanced a theory to explain the nonavailability of manganese after liming. They stated that there is an autoxidation of the available divalent manganese to insoluble or nonavailable manganese dioxide at a pH value above eight. In less alkaline soils the divalent manganese is oxidized to nonavailable trivalent manganese oxide. Manganese availability is also discussed by Sherman (52), Leeper (23), and Steenbjerg (55) who attribute the decrease of manganese upon liming to the oxidation of the divalent form to a higher insoluble valency.

Lime Recommendation Procedures

Various methods of making liming recommendations have been used by different investigators. One of the first studies on the estimation of lime requirement was that of Veitch (61) in 1902. Veitch developed a method of predicting the lime requirement of a soil from the estimation of its acidity by titration with a standard solution of lime water. Other approximate methods of lime recommendation were devised by Truog (59) in 1915 and Comber (10) in 1920. Truog's test was based on the reaction of zinc sulfide with soil acids to form hydrogen sulfide which could be detected with lead acetate paper. Comber's principle was based on the solubility of iron in an acid soil. This soluble iron was detected with potassium thiocyanate, thus giving an estimate of the soil acidity. Later, Joffe (21) and Johnson (22) concluded that lime requirement could not be directly predicted from the pH value of a soil. Hardy (17) conducted an experiment on the sugar cane soils of Trinidad. From his results Hardy constructed simple empirical graphs correlating the lime requirement with the pH value of the experimental plots. Hardy and Lewis (18) developed a rapid electrometric method for measuring the lime requirement of soils. An evaluation of limestone for lime recommendations was developed by Schollenberger and Salter (49). This evaluation brought the variables of composition, time for the desired reaction, and fineness of materials together for the practical use of lime recommendations to farmers. Probably the most accurate means of estimating the lime requirements of soils was the chemical method devised by Peech and Bradfield (43). This method involves only a pH measurement of the soil along with the use of empirically determined constants.

EXPERIMENTAL PROCEDURE

Soil Types

The soils selected for this study differed widely in soil profile characteristics. Soils representative of the important agricultural areas of the state were chosen. There were nine soils of eight different soil types selected. The location and soil type of each of the test farms are shown in Table 1. Figure 1 shows the approximate location of these soils on an outline map of the state. In Table 2 the chemical analyses of the surface soils prior to lime treatment are presented for the nine different locations.

TABLE 1

Location and Soil Type of Experimental Plots

Farm Location by Towns	County	Soil Type
Princess Anne	Somerset	Mattapex silt loam
Salisbury	Wicomico	Matawan sandy loam
Cordova	Talbot	Matawan sandy loam
Chestertown	Kent	Sassafras silt loam
Marlboro	Prince George	Monmouth loamy sand
Jarretsville	Harford	Glenelg loam
Sparks	Baltimore	Chester silt loam
Frederick	Frederick	Duffield silt loam
Hagerstown	Washington	Emory silt loam

Figure 1

Geographical Location of Experimental Plots

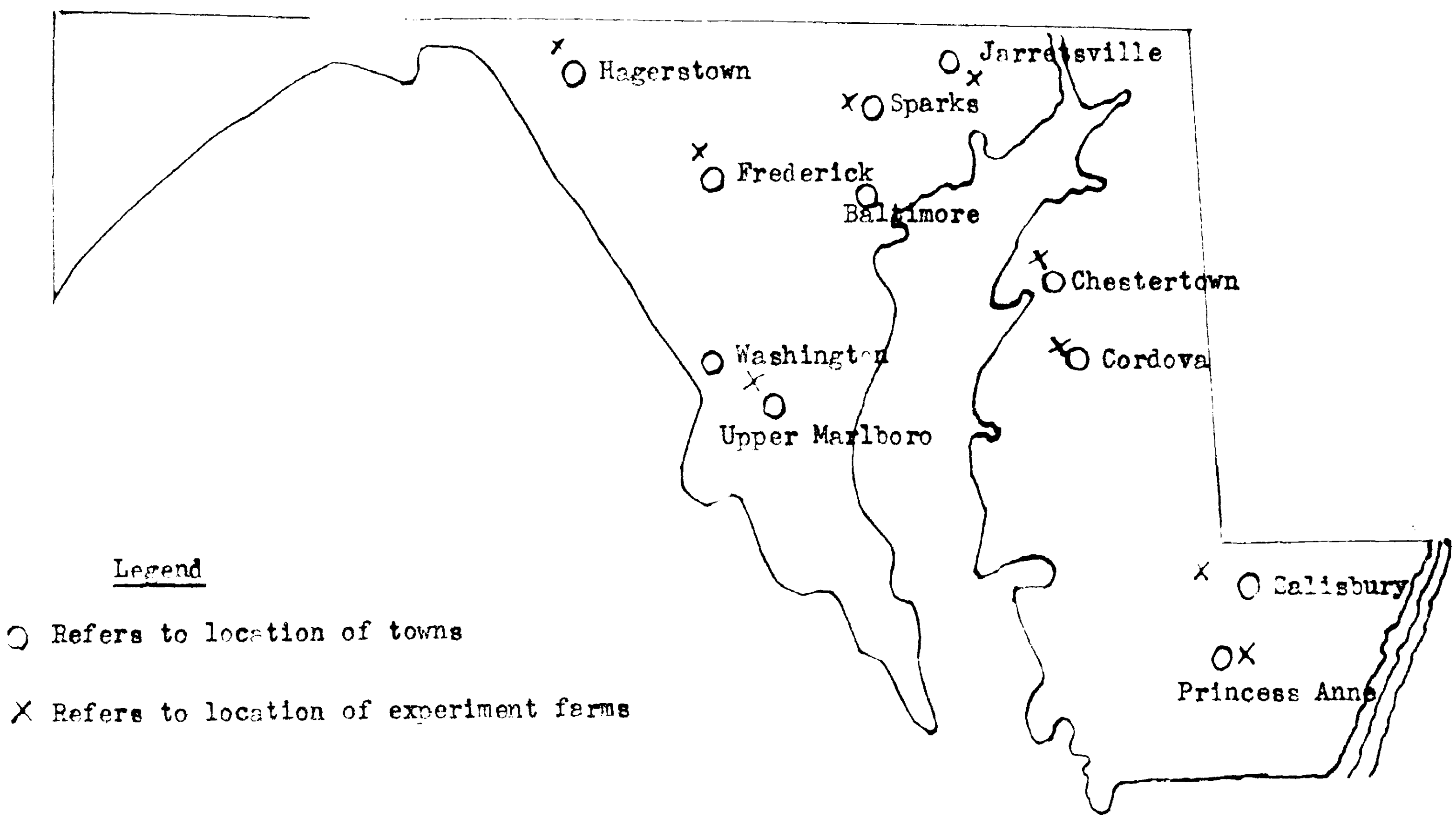


TABLE 2

Exchangeable Cations and Total Exchange Capacity of the Surface Soil on the Plot Areas Prior to Lime Treatment

Soils and Location	Exchange-able H	Exchange-able Ca	Exchange-able Mg	Exchange-able Mn	Exchange-able K	Total Exchange Capacity
	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm
Mattapex (Princess Anne)	6.22	2.61	0.57	0.02	0.09	9.51
Matawan (Salisbury)	1.26	2.01	0.86	0.00	0.08	4.21
Matawan (Cordova	2.48	1.85	0.31	0.00	0.20	4.84
Sassafras (Chestertown)	2.42	4.08	0.87	0.12	0.08	7.57
Monmouth (Marlboro)	4.47	5.37	0.63	0.03	0.71	11.21
Glenelg (Jarretsville)	4.07	3.90	0.69	0.02	0.20	8.38
Chester (Sparks)	6.13	7.47	0.90	0.09	0.60	15.19
Duffield (Frederick)	1.21	7.32	1.25	0.01	0.34	10.13
Emory (Hagerstown)	1.35	7.59	0.70	0.07	0.25	9.96

Liming Materials

Three chemical forms of agricultural liming material were used. The first form was ground limestone which is predominantly calcium carbonate. Ground limestone was chosen because it is the major liming material used in Maryland and could be obtained in varying degrees of fineness. This study included three grades of limestone whose sieve analyses are shown in Table 3.

TABLE 3

Sieve Analysis of the Three Limestone Grades
Used in the Liming Treatments

Grade	Percentage of Limestone Retained on the Different Screen Sizes *							
	6 Mesh	10 Mesh	35 Mesh	65 Mesh	100 Mesh	150 Mesh	200 Mesh	Thru 200 Mesh
Coarse	0	16.69	42.77	13.67	4.40	----	5.78	16.82
Medium	0	14.80	39.80	12.90	4.82	----	7.38	20.18
Fine	0	0	1.22	16.90	12.95	16.75	15.16	37.00

*18 mesh is equivalent to 1.0 mm. size opening.

Secondly, the burnt lime form of material, which is mostly calcium oxide obtained from the kiln-heating of limestone, was included in these field tests. The third material added was hydrated lime which is fundamentally calcium hydroxide. The latter two chemical forms are thought to give a more rapid reaction with the soil as they are more soluble than the limestone form.

Determination of Quantities of Lime Applied

Bray and Deturk (5) found that the sum of the calcium and magnesium on the exchange complex was approximately 80 per cent of the total exchange capacity of the soil at or near neutrality. As a starting point in this experiment this criterium was assumed to be the optimum condition. Thus, based on the chemical analysis of the untreated soil, and assuming complete solubility of the lime, the amount of lime necessary to attain an 80 per cent calcium plus magnesium saturation of the total exchange capacity was applied. Likewise, in a second treatment, enough lime to give a 160 per cent saturation of the total exchange capacity was applied. This gave two levels of chemically equivalent weights of the various materials so that the effect of quantity could be observed upon the soil. In the cases of Emory silt loam and Duffield silt loam, the soil already had a saturation of the exchange complex of 80 per cent. In these instances, the lighter treatments were omitted and only the heavier applications made.

Furthermore, based on the work of Loew (24), there are some who feel that the ratio of calcium to magnesium in the exchange complex might have an appreciable effect upon crop growth. In accordance with his views, this value was adjusted to an approximate 10:1 ratio so that this would not be a variable in the consideration of the results. The exchangeable calcium and magnesium was determined on the soil from each group of test plots. A mixture of high-calcium lime and dolomitic lime which would give a 10:1 ratio of calcium to magnesium in the exchange complex of soils was then applied.

Experimental Plots

The location, soil type, and crops of each of the test farms are shown in Table 4. The experimental plots on these farms were treated in 1947 with the exception of the farm near Marlboro. The plots on this farm were started in 1948. It was impossible to keep the method and time of application as invariables since the cooperating farms were under entirely different systems and farming practices. The method of application was necessarily changed in order to fit into the schedule and methods practiced by each of the individual farmers. In Table 5, a summary is presented of the application methods, the time of the application, and the number of test plots upon each of the test farms.

TABLE 4

Location of Plots, Soil Type and Crops Grown During First, Second and Third Year.

Farm Location by Towns	Soil Type	First Year Crop-1947	Second Year Crop-1948	Third Year Crop-1949
Princess Anne	Mattapex silt loam	Wheat	Timothy-clover	Pasture
Salisbury	Matawan sandy loam	Clover	Corn	Corn
Cordova	Matawan sandy loam	Corn	Wheat	Pasture
Chestertown	Sassafras silt loam	Corn	Wheat	Timothy-clover
Marlboro	Monmouth loamy sand	(No Crop)	Alfalfa	Alfalfa
Jarretsville	Glenelg loam	Timothy-clover	Corn	Wheat
Sparks	Chester silt loam	Corn	Wheat	Wheat
Frederick	Duffield silt loam	Clover	Corn	Barley
Hagerstown	Emory silt loam	Timothy-clover	Corn	Wheat

TABLE 5

Method of Lime Application, Time Applied, and Number of Plots Used In This Study.

Soil	Method of Application	Time Applied	Number of Plots
Mattapex silt loam Princess Anne	Top dressing to wheat	Apr. 26, 1947	44
Matawan sandy loam Salisbury	Top dressing to clover	May 2, 1947	44
Matawan sandy loam Cordova	Top dressing to plowed field and then disked in	Apr. 27, 1947	44
Sassafras silt loam Chestertown	Top dressing to plowed field and then disked in	May 5, 1947	44
Monmouth loamy sand Marlboro	One half disked in and then plowed under. Second half then thoroughly incorporated by disking	Aug. 25, 1948	44
Glenelg loam Jarretsville	Top dressing to hay crop	May 19, 1947	44
Chester silt loam Sparks	Top dressed and then ~~plowed~~ DISKED under	Apr. 11, 1947	44
Duffield silt loam Frederick	Top dressed to clover sod	Apr. 18, 1947	24
Emory silt loam Hagerstown	Top dressing to hay crop	May 10, 1947	24

Figures 2 through 10 show the patterns of the plot layouts on each farm. These plots were virtually one-hundredth of an acre, being 14 feet wide and 31 feet long. The plot treatments were not randomized, but were placed in a regular order. Each treatment was quadruplicated on every farm.

Soil Sampling Procedure

There was insufficient time to conduct a chemical analysis of all the plots on each farm so only one of the replicates of each treatment was sampled. The first sampling of the soil was undertaken two to four months after treatment which was usually after two or more good rains. The second soil sampling was made one year after liming. A third sampling was carried out after two years and a fourth sampling undertaken three years after liming. Since the plots on the Monmouth soil were started a year later, only three soil samplings were made here. Representative soil samples of these plots were collected by the method advocated by the A.O.A.C. (2) and taken to the laboratory for analysis. Both surface soil and subsoil were gathered from the treatments. The surface soil was taken with a soil auger at a depth of 0 to 6 inches on all but the Monmouth loamy sand. As this was a deeper soil it was sampled from 0 to 10 inches. The subsoil samples were taken at 6 to 12 inch depths in all plots except the Monmouth soil where a depth of 10 to 22 inches was sampled. The hydrated lime treatment on the Sassafras, Glenelg, and Chester soils and the fine grade of limestones on the Sassafras soil were sampled at regular depth intervals of 0 to 2-inches, 2 to 4 inches, 4 to 6 inches, and 6 to 10 inches, respectively, in order to determine the downward movement of lime in the soil.

Figure 2 Plot Designs Showing the Arrangement of Plots, Form of Lime, and Rate of Treatment on Mattapex Silt Loam, Matawan Sandy Loam (Salisbury), Matawan Sandy Loam (Cordova), and Sassafras Silt Loam

64 C - H	43	22 C - H	1
65 *	44 C - L	23	2 C - L
66 M - H	45	24 M - H	3
67	46 M - L	25	4 M - L
68 F - H	47	26 F - H	5
69	48 F - L	27	6 F - L
70 B - H	49	28 B - H	7
71	50 B - L	29	8 B - L
72 Hy - H	51	30 Hy - H	9
73	52 Hy - L	31	10 Hy - L
74 Check	53 Check	32 Check	11 Check
75 C - L	54	33 C - L	12
76	55 C - H	34	13 C - H
77 M - L	56	35 M - L	14
78	57 M - H	36	15 M - H
79 F - L	58	37 F - L	16
80	59 F - H	38	17 F - H
81 B - L	60	39 B - L	18
82	61 B - H	40	19 B - H
83 Hy - L	62	41 Hy - L	20
84	63 Hy - H	42	21 Hy - H

* Unlettered plots have other treatments not used in this study.

C refers to coarse ground limestone
M refers to medium ground limestone
F refers to fine ground limestone
B refers to burned lime
Hy refers to hydrated lime
H refers to heavy rate of lime calculated to give 160% exchange saturation
L refers to low rate of lime calculated to give 80% exchange saturation
Check refers to no lime treatment

Figure 3 Plot Design Showing the Arrangement of Plots, Forms of Lime, and Rate of Treatment on Monmouth Loamy Sand.

1 *	18 Hy - H	35	52 Hy - H
2 C - L	19	36 C - L	53
3	20 B - H	37	54 B - H
4 Check	21	38 M - L	55
5 M - L	22 F - H	39	56 F - H
6	23	40 F - L	57
7 F - L	24 M - H	41 B - L	58 M - H
8 B - L	25 C - H	42 Hy - L	59 C - H
9 Hy - L	26 Check	43	60 Hy - L
10	27 Hy - L	44 C - H	61
11 C - H	28	45	62 B - L
12	29 B - L	46 Check	63
13 M - H	30	47 M - H	64 F - L
14	31 F - L	48	65 Check
15 F - H	32	49 F - H	66
16 B - H	33 M - L	50 B - H	67 M - L
17 Hy - H	34 C - L	51 Hy - H	68 C - L

* Unlettered plots have other treatment not used in this study.

C refers to coarse ground limestone
M refers to medium ground limestone
F refers to fine ground limestone
B refers to burned lime
Hy refers to hydrated lime
H refers to heavy rate of lime calculated to give 160% exchange saturation
L refers to low rate of lime calculated to give 80% exchange saturation
Check refers to no lime treatment

Figure 4 Plot Design Showing the Arrangement of Plots, Forms of Lime, and Rate of Treatment on Glenelg Loam.

21 Check	42 Hy - H	63	84 Check
20 Hy - H	41	62 Hy - L	83
19 *	40 Hy - L	61	82 Check
18 B - H	39	60 B - H	81 Check
17	38 B - L	59	80 B - L
16 F - H	37	58 F - H	79
15	36 F - L	57	78 F - L
14 M - H	35	56 M - H	77
13	34 M - L	55	76 M - L
12 C - H	33	54 C - H	75
11	32 C - L	53	74 C - L
10 Hy - L	31	52 Hy - L	73
9	30 Hy - H	51	72 Hy - H
8 B - L	29	50 B - L	71
7	28 B - H	49	70 B - H
6 F - L	27	48 F - L	69
5	26 F - H	47	68 F - H
4 M - L	25	46 M - L	67
3	24 M - H	45	66 M - H
2 C - L	23	44 C - L	65
1	22 C - H	43	64 C - H

* Unlettered plots have other treatments not used in this study.

C refers to coarse ground limestone
M refers to medium ground limestone
F refers to fine ground limestone
B refers to burned lime
Hy refers to hydrated lime
H refers to heavy rate of lime calculated to give 160% exchange saturation
L refers to low rate of lime calculated to give 80% exchange saturation
Check refers to no lime treatment

FIGURE 5

Plot Design Showing The Arrangement of Plots, Forms of Lime, and Rate of Treatment on Chester Silt Loam.

22 F - L	21	20 Hy-L	19	18 B - L	17	16 C - L	15	14 M - L	13	12 F - L	11	10 Hy-L	9	8 B - L	7	6 C - L	5	4 M - L	3 *	2 F - L	1 Check
64	63 Hy-H	62	61 B - H	60	59 C - H	58	57 M - H	56	55 F - H	54	53 Hy-H	52	51 B - H	50	49 C - H	48	47 M - H	46	45 F - H	44	43 Check

42 Check	41	40 Hy-L	39	38 B - L	37	36 C - L	35	34 M - L	33	32 F - L	31	30 Hy-L	29	28 B - L	27	26 C - L	25	24 M - L	23
84 Check	83 Hy-H	82	81 B - H	80	79 C - H	78	77 M - H	76	75 F - H	74	73 Hy-H	72	71 B - H	70	69 C - H	68	67 M - H	66	65 F - H

* Unlettered plots have other treatment not used in this study
C refers to coarse ground limestone
M refers to medium ground limestone
F refers to fine ground limestone
B refers to burned lime
Hy refers to hydrated lime
H refers to heavy rate of lime calculated to give 160% exchange saturation
L refers to low rate of lime calculated to give 80% exchange saturation
Check refers to no lime treatment

Figure 6 Plot Design Showing The Arrangement of Plots, Forms of Lime, and Rate of Treatment on Duffield Silt Loam.

1 *	12 C - H	23	34 C - H
2 C - H	13	24 C - H	35
3	14 M - H	25	36 M - H
4 M - H	15	26 M - H	37
5	16 F - H	27	38 F - H
6 F - H	17	28 F - H	39
7 Check	18 Check	29 Check	40 Check
8 B - H	19	30 B - H	41
9	20 B - H	31	42 B - H
10 Hy - H	21	32 Hy - H	43
11	22 Hy - H	33	44 Hy - H

* Unlettered plots have other treatments not used in this study.

C refers to coarse ground limestone
M refers to medium ground limestone
F refers to fine ground limestone
B refers to burned lime
Hy refers to hydrated lime
H refers to heavy rate of lime calculated to give 160% exchange saturation
Check refers to no lime treatment

Figure 7 Plot Design Showing The Arrangement of Plots, Forms of Lime, and Rate of Treatment on Emory Silt Loam.

1 Check	12	23 C - H	34
2 C - H	13 C - H	24	35 C - H
3 *	14	25 M - H	36
4 M - H	15 Check	26	37 M - H
5	16 M - H	27 Check	38 Check
6 F - H	17	28 F - H	39
7	18 F - H	29	40 F - H
8 B - H	19	30 B - H	41
9	20 B - H	31	42 B - H
10 Hy - H	21	32 Hy - H	43
11	22 Hy - H	33	44 Hy - H

* Unlettered plots have other treatments not used in this study.

C refers to coarse ground limestone
M refers to medium ground limestone
F refers to fine ground limestone
B refers to burned lime
Hy refers to hydrated lime
H refers to heavy rate of lime calculated to give 160% exchange saturation
Check refers to no lime treatment

Laboratory Procedure

To investigate the effects of liming on the replaceable cations and the pH values the following procedure was used: The soil samples were air-dried, passed through a 10-mesh sieve, and mixed to give a uniform sample. The pH values were run with a Beckman pH meter using a 2:1 soil to water ratio as outlined by Mason and Obenshain (31). The laboratory determinations of exchangeable cations were made for all soil types on samples taken two to four months after the liming material had been applied. In addition, the Sassafras silt loam at Chestertown and the lighter textured Monmouth loamy sand at Marlboro were also analyzed one year and two years after the liming. These sampling intervals were used to investigate the influence of the form of lime, in relation to time, on cations of the various soils studied. Since no effect of liming was observed on the exchangeable potassium in the first soil sampling, this cation was omitted in the subsequent analyses. The validity of this omission was supported by work of Sen Gupta (51) on a Beltsville silt loam soil in Maryland. The ammonium acetate method of Schollenberger and Simon (50) was used in leaching the soil to replace the exchangeable cations. Schollenberger's procedure was also employed to determine the exchangeable hydrogen, calcium, and manganese. Magnesium was determined by the titan yellow method advocated by Gillam (15). Determination of potassium was made by the flamephotometer. The flamephotometer was also used in analyzing the total exchange capacity. In this method the soil was saturated with potassium by leaching with 1 N potassium chloride and then washing with alcohol until no test was given for chlorides. This potassium was displaced by ammonium ions and subsequently determined by the flamephotometer.

The pH values were determined on soil samples taken in 1947, 1948, 1949 and 1950. Exchangeable hydrogen, calcium, magnesium, manganese, and potassium were determined for all soils in the year that the lime was applied. Hydrogen, calcium, magnesium, manganese and pH values were determined on the 1947, 1948, and 1949 samples of Sassafras silt loam, and on the 1948, 1949, and 1950 samples of the Monmouth loamy sand. All of these analyses were carried out in duplicate.

Method of Reporting Crop Yields

Harvest yields were obtained from each plot in order to study the influence of the various liming materials on the crops. These yields were taken for all farms over a three-year period except for the Glenelg soil where only two years' results were obtained and the Monmouth soil for which only one year's yields were taken. Both the corn and hay yields were corrected to a 20 per cent moisture basis. All results reported are an average of four replicates. As these plots were not randomized, statistical treatment could not be applied to the results. The crop yields were compared with the corresponding pH values of the soil.

RESULTS

pH Determinations

The soil pH values of the plots from all of the farms are presented in Tables 6 through 14. The results in these tables are for both the surface soil and subsoil. The data in Tables 9 and 10 are plotted in Figures 8 and 9. These figures seemed to be representative of the graphs of pH versus lime treatment for all soils studied.

A summary of the effect of light and heavy lime applications on the pH values of the surface soil is presented in Tables 15 through 18. These data show the influence of the different liming treatments, the difference between soil types, and the effect of time on the pH value of limed soils.

For light applications the results indicate that all of the liming materials increased the soil pH values significantly above the values of the untreated plots. Also the light lime applications of hydrated and fine limestone treatments showed a significantly higher soil pH than the coarse and medium limestones. The burnt lime produced a soil pH which was not as high as the pH from the hydrated and fine limestones but higher than the soil pH produced by the medium and coarse limestone, however it was not significantly different from any other treatment except the untreated plot.

For the heavy lime applications a significant soil pH increase was shown by all liming materials above the soil pH of the untreated plots. The hydrated lime gave a significant increase in soil pH over the three limestone treatments, but not over the burnt lime treatment. Although burnt lime tended to increase the soil pH above the values from the limestone treatments, this increase was not significant. There was

TABLE 6

The pH Values As Influenced By Different Liming Treatments On Mattapex Silt Loam Soil, 1947 to 1949. (Princess Anne)

Treatment	Lime Applied Tons/Acre	Time Elapsed Between Liming Treatment and The Soil Sampling							
		Surface Soil				Subsoil			
		2 Months	1 Year	2 Years	3 Years	2 Months	1 Year	2 Years	3 Years
Coarse Limestone	1.65 x	4.97	5.21	5.05	5.49	4.76	5.17	5.00	5.01
	4.35 xx	5.80	5.82	5.03	5.72	4.81	5.32	4.90	5.02
Medium Limestone	1.70	5.45	5.20	5.00	5.03	4.85	4.99	5.02	5.09
	4.40	4.89	5.57	5.12	6.19	4.89	4.98	5.05	5.29
Fine Limestone	1.75	5.34	5.18	5.92	5.98	4.76	4.94	5.20	5.22
	4.80	4.97	5.37	5.21	5.85	4.75	5.12	4.80	5.06
Burnt Lime	1.15	5.38	5.56	4.96	5.03	4.71	5.05	4.93	5.09
	3.00	5.24	5.46	5.20	5.74	4.65	5.03	4.74	5.10
Hydrated Lime	1.20	5.27	5.22	5.25	5.71	4.88	4.34	4.70	5.02
	3.15	6.39	5.72	5.10	7.25	4.68	5.32	5.00	5.71
Untreated	0.00	4.64	5.00	4.85	4.31	4.57	5.06	4.89	5.00

x All of the lighter applications are in chemically equivalent amounts.
xx All of the heavier applications are in chemically equivalent amounts.

TABLE 7

The pH Values As Influenced By Liming Treatments on Matawan Sandy Loam Soil Over A Three Year Period. (Salisbury)

Treatment	Lime Applied Tons/Acre	Time Elapsed Between Liming Treatments And The Soil Sampling						
		Surface Soil				Subsoil		
		2 Months	1 Year	2 Years	3 Years	1 Year	2 Years	3 Years
Coarse Limestone	0.62 2.25	6.58 6.64	6.18 6.26	6.50 6.85	6.98 6.90	6.31 6.34	5.15 6.30	7.06 6.87
Medium Limestone	0.62 2.25	6.76 -	6.25 6.41	6.60 7.08	6.73 7.29	6.11 5.60	6.02 6.10	6.68 6.99
Fine Limestone	0.62 2.25	6.84 6.37	6.20 6.56	6.79 7.02	6.80 7.39	5.90 5.95	6.35 6.25	6.79 7.44
Burnt Lime	0.43 1.55	6.36 -	6.09 6.40	6.85 7.30	6.51 7.20	6.09 5.72	5.95 6.10	6.70 7.10
Hydrated Lime	0.50 1.30	6.94 7.05	6.06 6.51	6.59 6.75	7.83 7.39	5.99 6.23	5.70 5.60	6.26 7.16
Untreated	0.00	6.49	5.76	6.50	6.75	5.62	5.38	6.10

TABLE 8

The pH Values As Influenced By Liming Treatments On Matawan Sandy Loam Soil Over A Three Year Period. (Cordova)

Treatment	Lime Applied Ton/Acre	Time Elapsed Between Liming Treatment And The Soil Sampling						
		Surface Soil				Subsoil		
		4 Months	1 Year	2 Years	3 Years	1 Year	2 Years	3 Years
Coarse Limestone	0.85	5.74	6.02	5.68	5.82	6.25	6.18	5.43
	2.78	5.93	6.46	5.84	5.45	6.52	6.12	6.39
Medium Limestone	0.85	5.76	6.16	5.88	5.65	6.32	5.92	6.06
	2.78	6.17	6.36	5.55	6.41	6.09	5.93	6.40
Fine Limestone	0.85	5.94	6.40	5.96	5.53	6.41	6.15	6.58
	2.78	6.53	6.40	6.10	6.92	6.46	6.08	6.59
Burnt Lime	0.47	6.05	5.91	5.75	5.29	6.18	5.90	5.78
	1.71	6.52	6.85	6.00	6.36	6.62	6.15	6.39
Hydrated Lime	0.67	6.15	6.24	5.80	5.45	6.32	6.17	5.96
	2.18	7.16	6.83	5.71	6.99	6.34	5.76	6.79
Untreated	0.00	5.90	5.90	5.48	5.22	5.99	5.64	5.31

TABLE 9

The pH Values As Influenced By Liming Treatments On Sassafras Silt Loam Soil Over A Three Year Period. (Chestertown)

Treatment	Lime Applied Ton/Acre	Time Elapsed Between Liming Treatment And The Soil Sampling						
		Surface Soil				Subsoil		
		4 Months	1 Year	2 Years	3 Years	1 Year	2 Years	3 Years
Coarse Limestone	1.15	5.49	5.75	5.60	5.47	-	5.65	6.06
	3.65	6.00	6.56	5.95	6.25	6.00	5.70	6.21
Medium Limestone	1.15	5.90	6.09	5.70	6.10	6.23	6.00	6.09
	3.65	5.86	6.56	6.12	6.19	6.42	6.14	6.47
Fine Limestone	1.15	6.29	6.43	5.74	5.82	6.06	6.10	6.02
	3.65	6.81	6.66	6.60	6.50	6.38	6.05	6.79
Burnt Lime	0.70	6.25	6.21	5.50	5.69	5.83	5.80	5.99
	2.25	6.84	6.83	6.32	6.79	6.62	6.70	6.97
Hydrated Lime	0.95	6.06	6.72	5.60	5.62	6.26	5.80	6.73
	2.85	7.01	6.85	6.45	7.17	6.24	6.58	6.80
Untreated	0.00	5.44	5.75	5.05	5.48	5.95	5.50	5.41

Figure 8

The Relationship Between Five Forms of Lime Applied to Sassafras Silt Loam Surface Soils and the Resulting pH After Each of Four Different Periods

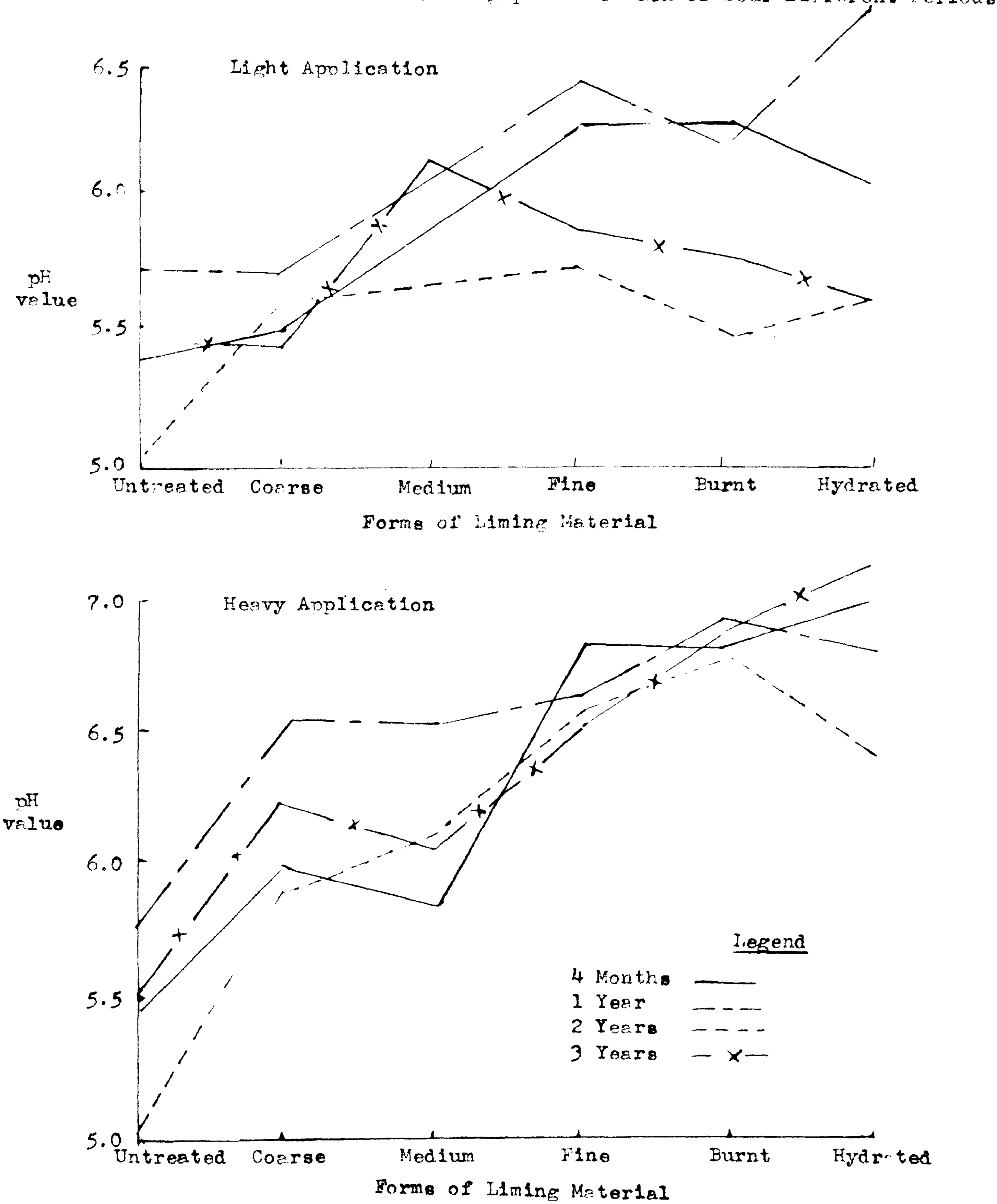


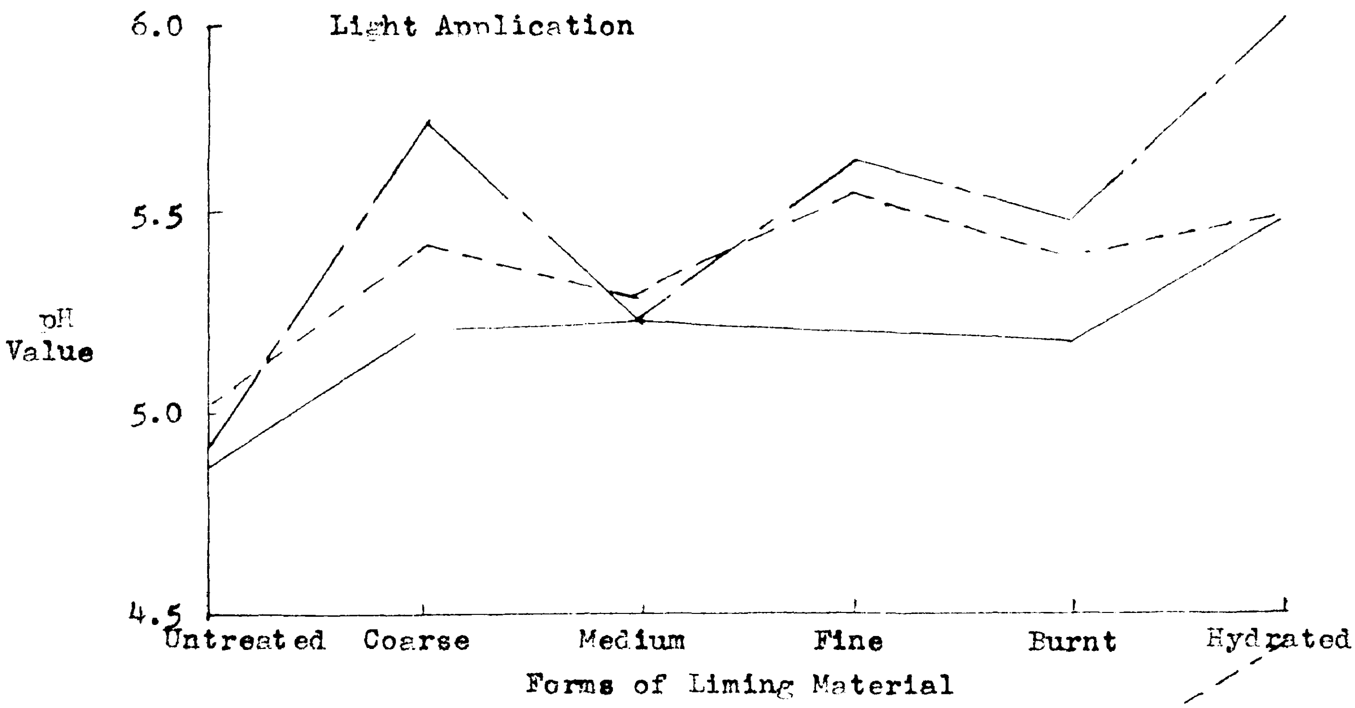
TABLE 10

The pH Values As Influenced By Liming Treatments On Monmouth Loamy Sand Soil Over A Two Year Period. (Marlboro)

Treatment	Lime Applied Ton/Acre	Time Elapsed Between Liming Treatment And The Soil Sampling					
		Surface Soil			Subsoil		
		2 Months	1 Year	2 Years	2 Months	1 Year	2 Years
Coarse Limestone	1.47	5.22	5.75	5.45	4.82	4.90	4.92
	5.54	5.81	6.10	6.20	5.51	5.55	5.30
Medium Limestone	1.47	5.25	5.25	5.30	5.29	5.08	4.90
	5.54	5.85	5.85	5.95	5.13	5.81	5.05
Fine Limestone	1.47	5.22	5.65	6.[illegible]9	4.75	5.10	5.39
	5.54	5.68	6.50	6.45	4.99	6.30	5.18
Burnt Lime	0.98	5.19	5.52	5.43	5.08	4.90	5.10
	3.50	6.65	6.80	7.10	5.58	6.00	5.52
Hydrated Lime	1.18	5.51	6.02	6.00	5.26	4.96	5.12
	4.38	6.78	7.00	7.50	5.89	6.15	6.20
Untreated	0.00	4.89	4.95	5.02	5.17	4.95	4.95

Figure 9

The Relationship Between Five Forms of Lime Applied to Monmouth Loamy Sand Surface Soils and the Resulting pH After Each of Three Different Periods



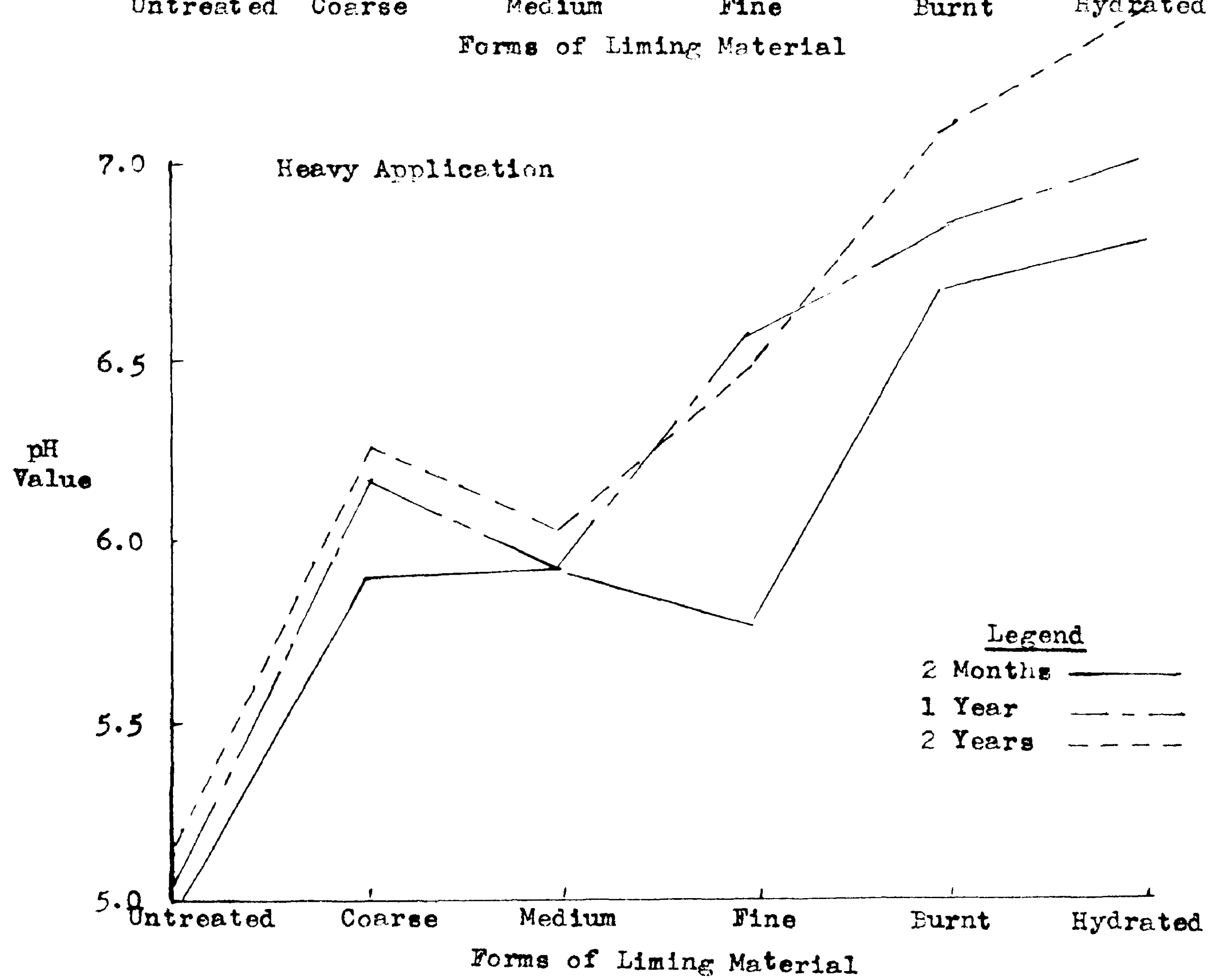


TABLE 11

The pH Values As Influenced by Liming Treatments on Glenelg Loam Soil Over a One Year Period. (Jarretsville)

Treatment	Lime Applied Ton/Acre	Time Elapsed Between Liming Treatments and The Soil Sampling.			
		Surface Soil		Subsoil	
		4 Months	1 Year	4 Months	1 Year
Coarse Limestone	1.25	5.83	——	5.59	——
	4.90	5.86	——	5.49	——
Medium Limestone	1.25	5.51	5.95	5.34	5.53
	4.90	5.46	5.80	5.21	5.24
Fine Limestone	1.25	5.54	5.79	5.64	5.40
	4.90	6.69	6.21	5.49	6.25
Burnt Lime	0.88	5.56	5.81	5.28	6.02
	4.00	5.50	5.72	5.76	5.28
Hydrated Lime	1.00	5.53	5.77	5.74	5.06
	3.50	5.79	6.86	6.42	6.27
Untreated	0.00	5.47	5.90	5.21	5.81

TABLE 12

The pH Values As Influenced By Liming Treatments on Chester Silt Loam Soil Over A Three Year Period. (Sparks)

Treatment	Lime Applied Ton/Acre	Time Elapsed Between Liming Treatment And The Soil Sampling							
		Surface Soil				Subsoil			
		4 Months	1 Year	2 Years	3 Years	4 Months	1 Year	2 Years	3 Years
Coarse Limestone	0.68	6.05	6.49	6.70	6.70	5.80	6.29	6.37	6.55
	5.50	6.50	6.31	6.70	7.12	6.10	6.17	6.39	6.70
Medium Limestone	0.68	6.20	6.57	6.70	6.86	6.10	6.29	6.60	6.60
	4.55	7.40	7.49	7.43	7.26	7.40	7.42	7.45	7.40
Fine Limestone	0.68	6.40	6.51	6.70	6.95	6.20	6.57	6.50	6.69
	4.55	6.60	6.41	6.90	7.15	6.05	6.26	6.31	6.81
Burnt Lime	0.42	6.60	6.49	7.07	7.08	6.05	6.22	6.82	6.67
	2.75	6.98	7.01	7.10	7.22	5.70	6.15	6.50	7.12
Hydrated Lime	0.53	6.35	6.43	7.01	6.91	6.39	6.89	6.70	6.69
	3.85	7.37	7.38	7.41	7.42	6.40	7.09	6.91	7.28
Untreated	0.00	5.80	5.90	6.32	6.28	5.55	5.78	6.22	5.91

TABLE 13

The pH Values As Influenced By Liming Treatments On Duffield Silt Loam Soil Over A Three Year Period. (Frederick*)

Treatment	Lime Applied Ton/Acre	Time Elapsed Between Liming Treatments And The Soil Sampling — Surface Soil				Subsoil			
		2 Months	1 Year	2 Years	3 Years	2 Months	1 Year	2 Years	3 Years
Coarse Limestone	3.95	7.60	7.51	7.35	7.55	7.20	7.24	7.25	7.28
Medium Limestone	3.95	7.30	7.30	6.80	7.38	7.30	7.01	6.89	7.22
Fine Limestone	3.95	7.30	7.30	7.05	7.45	7.10	6.98	6.92	7.10
Burnt Lime	2.40	7.10	6.93	6.85	7.28	6.60	7.37	6.80	7.09
Hydrated Lime	3.05	7.40	7.50	6.80	7.63	7.20	7.50	6.82	7.48
Untreated	0.00	6.60	6.68	6.55	6.75	6.64	6.71	6.45	6.99

* One weight-level only of liming material applied on this farm.

TABLE 14

The pH Values As Influenced By Liming Treatments On Emory Silt Loam Soil Over A Three Year Period. (Hagerstown*)

Treatment	Lime Applied Ton/Acre	Time Elapsed Between Liming Treatment And The Soil Sampling							
		Surface Soil				Subsoil			
		2 Months	1 Year	2 Years	3 Years	2 Months	1 Year	2 Years	3 Years
Coarse Limestone	4.05	6.79	7.10	7.01	7.06	----	6.53	6.70	7.09
Medium Limestone	4.15	7.00	7.10	7.20	7.21	7.00	7.01	7.04	7.39
Fine Limestone	4.45	6.81	7.08	7.15	7.50	6.81	6.90	6.92	7.20
Burnt Lime	2.80	7.56	7.63	7.68	7.82	7.67	7.47	7.60	7.71
Hydrated Lime	2.90	7.69	6.79	7.65	7.91	7.72	7.61	7.71	7.96
Untreated	0.00	6.70	6.77	6.80	6.79	6.88	6.66	6.60	6.71

* One weight-level only of liming material applied on this farm.

TABLE 15

Effect of Light Lime Applications on pH Values Compiled for All Sampling Dates as Averaged for Mattapex, Matawan (Salisbury), Matawan (Cordova), Sassafras, and Chester Soil Series.

Treatments	Dates				Average pH for Treatment
	2 to 4 Months	1 Year	2 Years	3 Years	
Coarse Limestone	5.78	5.94	5.92	6.10	5.94
Medium Limestone	6.04	6.08	5.98	5.98	6.02
Fine Limestone	6.14	6.14	6.22	6.22	6.18
Burnt Lime	6.16	6.06	6.06	5.92	6.05
Hydrated Lime	6.18	6.12	6.06	6.30	6.17
Untreated	5.64	5.68	5.66	5.72	5.68
Average pH for date	5.99	6.00	5.98	6.04	

L.S.D. (between treatments) = 0.15

No significant difference between dates

TABLE 16

Effect of Light Lime Application on pH Values as Averaged for All Sampling Dates for Mattapex, Matawan (Salisbury), Matawan (Cordova), Sassafras, and Chester Soil Series.

Treatment	Soil Series					Average pH for Treatment
	Mattapex	Matawan (Salisbury)	Matawan (Cordova)	Sassafras	Chester	
Coarse Limestone	5.20	6.58	5.80	5.60	6.50	5.94
Medium Limestone	5.18	6.60	5.78	5.95	6.60	6.02
Fine Limestone	5.60	6.65	5.95	6.05	6.65	6.18
Burnt Lime	5.25	6.48	5.78	5.93	6.83	6.05
Hydrated Lime	5.38	6.35	5.93	6.00	6.68	6.17
Untreated	4.83	6.40	5.63	5.45	6.08	5.68
Average pH for soil series	5.24	6.59	5.81	5.83	6.55	

L.S.D. (between farms) = 0.14

TABLE 17

Effect of Heavy Lime Application on pH Values Compiled for All Sampling Dates as Averaged for Mattapex, Matawan (Cordova), Sassafras, Chester, Duffield and Emory Soil Series.

Treatment	Dates				Average pH for Treatment
	2 to 4 Months	1 Year	2 Years	3 Years	
Coarse Limestone	6.43	6.72	6.32	6.55	6.50
Medium Limestone	6.45	6.75	6.37	6.78	6.59
Fine Limestone	6.50	6.55	6.52	6.92	6.62
Burnt Lime	6.70	6.78	6.62	6.87	6.74
Hydrated Lime	7.18	6.85	6.53	7.40	6.99
Untreated	5.83	6.02	5.87	5.90	5.90
Average pH for date	6.52	6.61	6.37	6.74	

L.S.D. (between treatments) = 0.28

L.S.D. (between dates) = 0.12

TABLE 18

Effect of Heavy Lime Applications on pH Values as Averaged for All Sampling Dates for Mattapex, Matawan (Cordova), Sassafras, Chester, Duffield and Emory Soil Series.

Treatment	Soil Series						Average pH for Treatment
	Mattapex	Matawan (Cordova)	Sassafras	Chester	Duffield	Emory	
Coarse Limestone	5.58	5.93	6.23	6.78	7.53	7.00	6.50
Medium Limestone	5.45	6.15	6.20	7.40	7.20	7.13	6.59
Fine Limestone	5.38	6.48	6.65	6.78	7.30	7.15	6.62
Burnt Lime	5.40	6.45	6.80	7.08	7.05	7.68	6.74
Hydrated Lime	6.13	6.68	6.90	7.40	7.33	7.53	6.98
Untreated	4.83	5.63	5.45	6.08	6.68	6.78	5.90
Average pH for soil series	5.46	6.22	6.37	6.92	7.18	7.21	

L.S.D. (between farms) = 0.28

no significant pH increase resulting from any one fineness grade of limestone above that of any other limestone grade in these heavy lime treatments.

It has been shown that all the lime treatments employed in this investigation increased the soil pH significantly above the values of the untreated plots. The amount of liming material applied influenced the pH value of the soil. As would be expected from the law of mass action, each of the soils showed a larger pH increase from the heavier lime applications. In general, there was not much difference shown within the different lime treatments. The soils treated with hydrated lime were an exception to this generalization. The reason for the greater action of the hydrated form of lime is probably twofold; the hydrated lime was more soluble than the carbonate form of lime and its extremely fine state of division was thought to give it a larger effective surface area.

Burnt lime did not tend to change the pH values as much as the hydrated form although the difference was not statistically significant. This trend was thought to be due to the greater degree of fineness of the hydrated lime and the tendency of the burnt lime to aggregate, or plaster itself into larger particles when it contacted the moist soil. A comparison of heavy application of burnt lime and the limestones generally showed greater pH changes for the burnt lime, but the differences were not statistically significant. This pH effect was attributed to the fact that burnt lime is more soluble than the limestone. The trend from the results of the heavy lime treatments indicate that the soil reaction is influenced the most by the hydrated lime, secondly by the burnt lime, and to the least extent by the limestones. This trend is shown in Tables 17 and 18 compiled from the soils studied and the sequence is better illustrated by the Sassafras and Monmouth soils of Figures 8 and 9. These figures of

Sassafras and Monmouth soils are generally representative of the graphs of pH plotted against lime treatment for all soils studied.

The influence of the degree of fineness of the limestone upon the soil reaction is included in Tables 6 through 14. Only the light application of fine limestone gave a significant pH effect among the limestone treatments. In general, however, there was a trend toward slightly larger increases in pH values with an increase in the state of division. This greater reaction could be predicted due to the increased solubility resulting from the larger surface area. It should be mentioned that the fine limestone was from a different source than the coarse and medium limestones so that a possible solubility difference might exist between the limestones of different sources.

The work of Lyon (25) at Cornell has indicated that the degree of fineness has a much larger effect upon the pH change than this experimental data for the heavier lime applications exhibits. This difference might be explained by an examination of the sieve size analysis of the three limestones as previously given in Table 3. The coarse limestone and medium limestone are too similar in analysis to give an extensive difference. In all three grades of limestone used, there was a large amount of the finest portion, i.e., the portion which passes through a 200-mesh sieve. This is believed to be the situation encountered by the farmer when he purchases well-ground limestone. When these limestones were applied to the soil in large quantities as used in this experiment, there was an excess of this finer material which could saturate the soil solution and give similar results upon the soil reaction. In investigations upon the effect of fineness of limestone, such as Lyon's study, the limestones used were screened so that each tested material was all of the same approximate diameter. These sieve separates gave quite an appreciable difference in pH value of a soil when compared to another size range of limestone.

A highly significant difference was shown between the soil pH values of the various soil types which were similarly limed. Since the liming materials were added in amounts that were calculated to raise the soil pH to the same approximate value for all soils this significant difference which resulted was unexpected. There are apparently two reasons for this difference between soils. First, there was a relation shown between the initial soil pH prior to liming and the soil pH after liming. Soils with a low initial pH value did not respond as much as those soils of a higher initial pH even though more liming material was added. This is in agreement with data published by Ohio (37) and Virginia (44) which showed that more lime is required to raise a soil pH one unit at a lower pH value than is needed to increase the same soil one pH unit at a higher pH value. Secondly, the two factors of slow solubility of the liming materials and the different amounts of applied lime could have influenced the replacement of exchangeable hydrogen of the soil. Thus it would seem that a lime recommendation method should include an empirical factor to compensate for this slow solubility. Such a factor is reported in the following section of, A Suggested Lime Recommendation Method.

Tables 15 and 17 also indicate the effect of time on the pH value of limed soils. No significant change in soil pH occurred between sampling dates for the light lime treatments during the three year period included in this study. For the heavy applications no significant difference was shown in soil pH measurements taken after the first few months and after one year. However, after two years a significant decrease occurred in soil pH value for the heavier lime treatments. At the end of three years this soil pH increased and was significantly higher than the soil pH at all previous sampling dates. However, the changes in soil pH between sampling dates was small and probably of little agronomic significance.

Exchangeable Cations

The values of the exchangeable cations as determined for all nine soils are reported in Tables 19 through 31. A statistical analyses of this data shows highly significant differences between the various soil types for all cations studied. This could be expected since the soils were different in exchange capacities as well as in their inherent states of fertility.

The effect of liming upon the pH value of a soil is related to the exchangeable hydrogen. A summary of the influence of both the light and heavy lime applications on the exchangeable hydrogen is presented in Tables 32 and 33.

Light applications of all three grades of limestone reduced the exchangeable hydrogen of the soil but the decreases were not significantly lower than the untreated plot values. In soils treated with light applications of hydrated and burnt lime the exchangeable hydrogen values were decreased significantly below the values of the untreated soils. Although the exchangeable hydrogen of the soil treated with hydrated lime was lower than the value of soils treated with burnt lime, this difference was not significant. A significant decrease was shown in exchangeable hydrogen for those soils treated with hydrated and burnt lime below the values for the soils treated with coarse limestone.

The soils treated with heavy applications of coarse and medium limestone, burnt lime, and hydrated lime all gave significant decreases in exchangeable hydrogen when compared with the exchangeable hydrogen values of the untreated soils. Fine limestone did not cause a significant decrease in exchangeable hydrogen below the value of soils which were untreated.

TABLE 19

The Exchangeable Cations As Influenced By Liming Treatments on Mattapex Silt Loam Surface Soil (Princess Anne)

Treatment	Lime Applied Tons/Acre	Exchangeable Cations After 2 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm	K m.e./100gm
Coarse Limestone	1.65	5.37	2.84	0.43	0.10	0.13
	4.35	2.30	5.80	0.53	0.01	0.13
Medium Limestone	1.70	4.64	4.31	0.55	0.11	0.13
	4.40	5.25	3.34	0.38	0.01	0.08
Fine Limestone	1.75	4.66	3.71	0.63	0.04	0.06
	4.80	4.57	2.61	0.57	0.01	0.10
Burnt Lime	1.15	2.75	5.49	0.76	0.03	0.07
	3.00	3.74	5.81	0.94	0.01	0.13
Hydrated Lime	1.20	4.64	3.50	0.91	0.02	0.03
	3.15	1.87	6.56	0.53	0.01	0.12
Untreated	0.00	6.22	2.61	0.57	0.02	0.09

TABLE 20

The Exchangeable Cations As Influenced By Liming Treatments On Mattapex Silt Loam Subsoil. (Princess Anne)

Treatment	Lime Applied Tons/Acre	Exchangeable Cations After 2 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm	K m.e./100gm
Coarse Limestone	1.65	5.57	2.20	0.27	0.08	0.07
	4.35	5.28	2.53	0.28	0.00	0.07
Medium Limestone	1.70	5.44	2.47	0.34	0.07	0.08
	4.40	5.10	2.66	0.42	0.00	0.08
Fine Limestone	1.75	5.59	2.23	0.32	0.02	0.04
	4.80	7.02	2.92	0.32	0.02	0.07
Burnt Lime	1.15	6.00	2.00	0.14	0.03	0.03
	3.00	6.02	3.52	0.36	0.01	0.11
Hydrated Lime	1.20	4.88	3.05	0.21	0.02	0.04
	3.15	6.94	2.70	0.75	0.00	0.08
Untreated	0.00	6.08	2.64	0.27	0.01	0.06

TABLE 21

The Exchangeable Cations As Influenced By Liming Treatments On Matawan Sandy Loam Surface Soil. (Salisbury)

Treatment	Lime Applied Tons/Acre	Exchangeable Cations After 2 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm	K m.e./100gm
Coarse Limestone	0.62	1.87	2.20	0.64	0.00	0.12
	2.25	2.08	2.06	0.48	0.00	0.04
Medium Limestone	0.62	1.45	2.13	0.77	0.00	0.07
	2.25	——	——	——	——	——
Fine Limestone	0.62	1.42	2.48	0.97	0.01	0.08
	2.25	1.80	1.76	0.47	0.00	0.06
Burnt Lime	0.43	1.83	1.76	0.61	0.01	0.08
	1.55	——	——	——	——	——
Hydrated Lime	0.50	1.29	2.28	0.79	0.00	0.06
	1.30	1.34	2.01	0.86	0.00	0.07
Untreated	0.00	2.16	2.01	0.86	0.00	0.08

TABLE 22

The Exchangeable Cations As Influenced By Liming Treatments On Matawan Sandy Loam Surface Soil. (Cordova)

Treatment	Lime Applied Tons/Acre	Exchangeable Cations After 4 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm	K m.e./100gm
Coarse Limestone	0.85	2.22	2.40	0.30	0.00	0.07
	2.78	1.81	2.50	0.64	0.03	0.09
Medium Limestone	0.85	1.63	2.46	0.38	0.00	0.06
	2.78	1.34	3.07	0.54	0.03	0.09
Fine Limestone	0.85	1.34	2.99	0.48	0.00	0.12
	2.78	1.28	2.92	1.72	0.04	0.11
Burnt Lime	0.47	1.10	3.58	0.36	0.02	0.07
	1.71	1.45	2.95	0.53	0.02	0.12
Hydrated Lime	0.67	1.99	3.09	0.54	0.00	0.07
	2.18	0.00	2.48	2.44	0.02	0.13
Untreated	0.00	1.67	2.53	0.51	0.02	0.10

TABLE 23

The Exchangeable Cations As Influenced By Liming Treatments and Time on Sassafras Silt Loam Surface Soil. (Chestertown)

Treatment	Lime Applied Tons/Acre	H m.e./100gm 4 Mos.	H 1 Year	H 2 Years	Ca m.e./100gm 4 Mos.	Ca 1 Year	Ca 2 Years	Mg m.e./100gm 4 Mos.	Mg 1 Year	Mg 2 Years	Mn m.e./100gm 4 Mos.	Mn 1 Year	Mn 2 Years	K m.e./100gm 4 Mos.
Coarse Limestone	1.15	2.40	——	2.57	3.84	——	4.05	1.04	——	0.67	0.18	——	0.02	0.12
	3.65	2.24	0.90	2.01	4.22	4.83	4.55	0.94	0.59	0.71	0.08	0.08	0.02	0.09
Medium Limestone	1.15	1.82	2.23	2.39	4.49	4.55	4.92	1.04	0.71	0.66	0.10	0.06	0.03	0.12
	3.65	——	0.80	1.51	——	5.52	5.65	——	0.63	0.58	——	0.07	0.04	——
Fine Limestone	1.15	1.35	——	2.55	4.98	——	4.52	1.03	——	0.71	0.09	——	0.03	0.12
	3.65	0.00	——	0.00	6.37	——	6.99	1.08	——	0.67	0.01	——	0.01	0.11
Burnt Lime	0.70	1.33	2.32	2.42	4.91	3.33	3.96	1.12	0.66	0.56	0.11	0.05	0.00	0.10
	2.25	0.00	0.00	0.00	6.04	6.83	6.59	1.41	0.82	0.74	0.03	0.05	0.04	0.09
Hydrated Lime	0.95	1.59	1.15	2.20	4.89	5.73	4.80	0.88	0.64	0.53	0.12	0.08	0.03	0.09
	2.85	0.00	0.80	0.57	6.12	6.38	6.78	1.24	0.71	0.56	0.05	0.08	0.01	0.16
Untreated	0.00	2.42	2.39	2.85	4.08	4.28	3.58	0.87	0.74	0.63	0.12	0.07	0.02	0.08

TABLE 24

The Exchangeable Cations As Influenced By Liming Treatments And Time On Sassafras Silt Loam Subsoil.(Chestertown)

Treatment	Lime Applied Tons/Acre	H m.e./100gm		Ca m.e./100gm		Mg m.e./100gm		Mn m.e./100gm	
		1 Year	2 Years	1 Year	2 Years	1 Year	2 Years	1 Year	2 Years
Coarse Limestone	1.15	—	2.35	—	4.48	—	1.04	—	0.00
	3.65	1.97	2.24	4.74	4.92	0.91	1.17	0.02	0.00
Medium Limestone	1.15	2.38	1.67	3.65	5.03	1.04	1.07	0.08	0.00
	3.65	1.94	1.55	4.85	5.38	0.95	1.20	0.02	0.00
Fine Limestone	1.15	1.75	1.53	5.38	4.43	0.63	0.91	0.06	0.02
	3.65	2.04	1.53	5.34	5.03	1.19	1.17	0.03	0.00
Burnt Limestone	0.70	1.99	2.26	4.48	3.74	0.64	0.66	0.06	0.01
	2.25	0.85	0.72	5.76	5.50	0.82	1.00	0.04	0.00
Hydrated Lime	0.95	1.61	2.27	4.20	3.92	0.82	0.72	0.07	0.00
	2.85	1.74	1.40	4.38	5.73	0.67	0.91	0.04	0.00
Untreated	0.00	2.37	2.31	4.29	4.08	0.81	1.07	0.03	0.00

TABLE 25

The Exchangeable Cations As Influenced By Liming Treatments On Monmouth Loamy Sand Surface Soil. (Marlboro)

Treatment	Lime Applied Tons/Acres	H m.e./100gm			Ca m.e./100gm			Mg m.e./100gm			Mn m.e./100gm		
		Mos. 2	Year 1	Years 2	Mos. 2	Year 1	Years 2	Mos. 2	Year 1	Years 2	Mos. 2	Year 1	Years 2
Coarse Limestone	1.47	2.89	2.11	2.41	5.90	5.30	4.68	1.61	2.43	1.19	0.03	0.[illegible]2	0.01
	5.54	2.01	2.03	1.46	5.11	5.20	5.75	0.95	0.74	0.74	0.03	0.02	0.01
Medium Limestone	1.47	3.26	2.92	3.13	4.80	3.86	3.51	0.62	1.77	0.66	0.06	0.03	0.01
	5.54	2.00	0.91	1.95	5.65	6.46	4.97	0.87	1.69	0.86	0.05	0.02	0.00
Fine Limestone	1.47	3.31	2.56	1.76	3.66	3.98	4.97	0.70	0.50	0.53	0.04	0.02	0.01
	5.54	2.91	1.14	1.11	5.09	5.55	5.25	2.00	1.97	1.48	0.02	0.01	0.00
Burnt Lime	0.98	2.20	2.83	2.48	3.71	3.57	3.45	0.62	0.58	0.95	0.04	0.02	0.01
	3.50	0.00	0.81	0.00	8.22	6.90	7.31	1.96	3.[illegible]7	1.77	0.00	0.00	0.00
Hydrated Lime	1.18	2.32	2.45	1.92	4.22	4.04	4.33	0.56	0.5[illegible]	0.66	0.03	0.02	0.00
	4.38	0.53	0.00	0.00	5.44	6.08	6.22	1.81	2.14	2.[illegible]	0.01	0.00	0.00
Untreated	0.00	3.35	3.16	3.69	3.28	3.45	3.39	0.58	1.28	0.74	0.06	0.03	0.01

TABLE 26

The Exchangeable Cations As Influenced By Liming Treatments On Monmouth Loamy Sand Subsoil. (Marlboro)

Treatment	Lime Applied Tons/Acre	H m.e./100gm 2 Mos.	H 1 Year	H 2 Years	Ca m.e./100gm. 2 Mos.	Ca 1 Year	Ca 2 Years	Mg m.e./100gm 2 Mos.	Mg 1 Year	Mg 2 Years	Mn m.e./100gm 2 Mos.	Mn 1 Year	Mn 2 Years
Coarse Limestone	1.47	5.13	4.18	4.15	6.60	7.14	6.44	1.00	1.50	1.93	0.00	0.01	0.01
	5.54	1.98	1.78	2.03	5.83	4.82	4.48	1.27	1.40	0.70	0.02	0.00	0.01
Medium Limestone	1.47	2.79	2.73	2.91	4.63	2.96	2.93	1.13	0.95	0.74	0.02	0.04	0.01
	5.54	4.14	1.73	2.94	5.09	5.65	4.57	1.81	2.10	1.15	0.02	0.01	0.00
Fine Limestone	1.47	3.83	3.22	2.19	4.28	2.95	3.74	1.10	0.49	0.58	0.03	0.02	0.01
	5.54	5.18	3.01	3.60	5.96	6.08	6.52	1.64	2.30	1.18	0.00	0.01	0.00
Burnt Lime	0.98	2.73	2.81	2.53	4.15	3.22	3.48	1.28	0.70	0.74	0.02	0.02	0.01
	3.50	3.08	1.54	2.65	5.37	6.15	6.20	1.00	3.61	2.10	0.00	0.01	0.00
Hydrated Lime	1.18	2.52	2.70	2.63	5.10	4.00	3.62	1.13	0.74	0.70	0.02	0.02	0.00
	4.38	2.20	1.45	1.35	6.06	5.91	5.45	2.25	1.93	1.97	0.00	0.00	0.00
Untreated	0.00	2.54	2.68	3.06	5.33	3.28	2.57	1.61	1.03	0.86	0.02	0.03	0.04

TABLE 27

The Exchangeable Cations As Influenced By Liming Treatments On Glenelg Loam Surface Soil. (Jarretsville)

Treatment	Lime Applied Tons/Acres	Exchangeable Cations After 4 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm	K m.e./100gm
Coarse Limestone	1.25	3.05	4.38	1.22	0.15	0.08
	4.90	2.67	4.67	1.35	0.10	0.09
Medium Limestone	1.25	3.41	4.75	1.45	0.07	0.15
	4.90	3.55	3.77	1.28	0.16	0.12
Fine Limestone	1.25	3.15	4.48	1.42	0.31	0.14
	4.90	3.17	5.09	0.78	0.20	0.10
Burnt Lime	0.88	3.14	4.34	1.11	0.17	0.12
	4.00	4.25	3.40	0.91	0.17	0.12
Hydrated Lime	1.00	2.98	4.49	1.17	0.13	0.11
	3.50	3.45	4.21	0.91	0.20	0.11
Untreated	0.00	3.02	4.70	0.70	0.18	0.11

TABLE 28

The Exchangeable Cations As Influenced By Liming Treatments On Chester Silt Loam Surface Soil. (Sparks)

Treatment	Lime Applied Tons/Acre	Exchangeable Cations After 4 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm	K m.e./100gm
Coarse Limestone	0.68	6.45	7.32	1.12	0.04	0.26
	5.50	3.78	9.86	1.22	0.07	0.26
Medium Limestone	0.68	3.72	9.74	1.49	0.04	0.20
	4.55	0.00	13.12	1.81	0.06	0.20
Fine Limestone	0.68	5.17	8.42	0.39	0.20	0.51
	4.55	4.15	7.76	2.86	0.08	0.34
Burnt Lime	0.42	5.78	5.18	1.12	0.00	0.21
	2.75	1.13	13.03	0.95	0.08	0.21
Hydrated Lime	0.53	2.46	7.30	1.05	0.14	0.16
	3.85	0.00	14.06	0.74	0.04	0.35
Untreated	0.00	6.13	7.47	0.90	0.09	0.60

TABLE 29

The Exchangeable Cations As Influenced By Liming Treatments On Chester Silt Loam Subsoil. (Sparks)

Treatment	Lime Applied Tons/Acre	Exchangeable Cations After 4 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm	K m.e./100gm
Coarse Limestone	0.68	5.28	5.25	0.66	0.07	0.15
	5.50	5.37	6.68	0.89	0.07	0.17
Medium Limestone	0.68	5.57	6.43	0.77	0.00	0.57
	4.55	1.76	10.50	1.87	0.02	0.14
Fine Limestone	0.68	6.55	7.12	0.53	0.02	0.37
	4.55	3.87	6.84	1.22	0.07	0.23
Burnt Lime	0.42	3.05	5.77	0.66	0.04	0.25
	2.75	5.26	6.76	1.05	0.07	0.16
Hydrated Lime	0.53	2.65	6.06	1.15	0.10	0.23
	3.[illegible]5	4.32	7.20	1.09	0.06	0.18
Untreated	0.00	6.14	6.42	0.44	0.09	0.16

TABLE 30

The Exchangeable Cations As Influenced By Liming Treatments On Duffield Silt Loam Soil.* (Frederick)

Treatment	Lime Applied Tons/Acre	Exchangeable Cations After 2 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e/100gm	K m.e./100gm
Coarse Limestone	3.95					
Surface Soil		0.00	9.07	1.44	0.09	0.15
Subsoil		0.85	9.05	1.19	0.13	0.25
Medium Limestone	3.95					
Surface Soil		0.00	9.28	1.07	0.11	0.29
Subsoil		0.35	8.95	1.03	0.09	0.09
Fine Limestone	3.95					
Surface Soil		0.00	9.21	1.07	0.11	0.36
Subsoil		0.85	8.45	0.95	0.18	0.13
Burnt Lime	2.40					
Surface Soil		0.89	9.00	1.52	0.09	0.15
Subsoil		1.70	7.66	0.86	0.14	0.13
Hydrated Lime	3.05					
Surface Soil		0.00	8.77	1.56	0.09	0.33
Subsoil		0.00	10.35	1.19	0.18	0.24
Untreated	0.00					
Surface Soil		1.65	7.37	1.24	0.08	0.46
Subsoil		0.22	8.36	0.99	0.05	0.27

* One weight-level only of liming material applied on this farm.

TABLE 31

The Exchangeable Cations As Influenced By Liming Treatments On Emory Silt Loam Soil. * (Hagerstown)

Treatment	Lime Applied Tons/Acre	Exchangeable Cations After 2 Months				
		H m.e./100gm	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm	K m.e./100gm
Coarse Limestone	4.05					
Surface Soil		0.00	7.66	1.82	0.02	0.46
Subsoil						
Medium Limestone	4.15					
Surface Soil		0.00	8.43	1.03	0.11	0.39
Subsoil		0.00	7.62	0.86	0.00	0.21
Fine Limestone	4.45					
Surface Soil		0.66	8.05	1.48	0.09	0.15
Subsoil		0.71	6.00	0.74	0.00	0.14
Burnt Lime	2.80					
Surface Soil		0.00	8.03	1.32	0.06	0.55
Subsoil		0.00	7.76	0.70	0.00	0.23
Hydrated Lime	2.90					
Surface Soil		0.00	6.99	2.59	0.07	0.31
Subsoil		0.00	6.89	1.64	0.00	0.16
Untreated	0.00					
Surface Soil		1.35	7.59	0.70	0.07	0.25
Subsoil		0.68	7.90	0.95	0.00	0.21

* One weight-level of liming material applied on this farm.

TABLE 32

Effect of Light Lime Treatments On Exchangeable Hydrogen for Mattapex, Matawan (Salisbury), Matawan (Cordova), Sassafras, Monmouth, Glenelg, and Chester Soil Series.

Soil Type	Treatments						Average Value For Soil Type
	Untreated	Coarse Limestone	Medium Limestone	Fine Limestone	Burnt Lime	Hydrated Lime	
	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100 gm	m.e./100gms
Mattapex Silt Loam	6.22	5.37	4.64	4.66	2.75	4.64	4.72
Matawan Sandy Loam (Salisbury)	2.16	1.87	1.45	1.42	1.83	1.29	1.67
Matawan Sandy Loam (Cordova)	1.67	2.22	1.63	1.34	1.10	1.99	1.66
Sassafras Silt Loam	2.42	2.40	1.82	1.35	1.33	1.59	1.82
Monmouth Loamy Sand	3.35	2.89	3.26	3.31	2.20	2.32	2.89
Glenelg Loam	3.02	3.05	3.41	3.15	3.14	2.98	3.13
Chester Silt Loam	6.13	6.45	3.72	5.17	5.78	2.46	4.95
Average Value for Treatment	3.55	3.47	2.85	2.91	2.59	2.46	

L.S.D. (Between Treatments) = 0.78

TABLE 33

Effect of Heavy Lime Treatments On Exchangeable Hydrogen for Mattapex, Matawan (Cordova), Monmouth, Glenelg, Chester, Duffield, and Emory Soil Series.

Soil Type	Treatment						Average Value For Soil Type
	Untreated	Coarse Limestone	Medium Limestone	Fine Limestone	Burnt Lime	Hydrated Lime	
	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm
Mattapex Silt Loam	6.22	2.30	5.25	4.57	3.74	1.87	3.99
Matawan Sandy Loam (Cordova)	1.67	1.81	1.34	1.28	1.45	0.00	1.26
Monmouth Loamy Sand	3.35	2.01	2.00	2.91	0.00	0.58	1.81
Glenelg Loam	3.02	2.67	3.55	3.17	4.25	3.45	3.35
Chester Silt Loam	6.13	3.78	0.00	4.15	1.13	0.00	2.53
Duffield Silt Loam	1.65	0.00	0.00	0.00	0.89	0.00	0.42
Emory Silt Loam	1.35	0.00	0.00	0.66	0.00	0.00	0.34
Average Value For Treatment	3.34	1.80	1.73	2.39	1.64	0.84	

L.S.D. (Between Treatments) = 1.22

Exchangeable calcium was the only cation other than the hydrogen ions to be significantly changed by heavy applications of liming materials. A summary of the results from the heavy lime applications on the exchangeable calcium are presented in Table 35. Here it can be seen that soils treated with burnt and hydrated lime gave significant increases of exchangeable calcium above the value of the untreated soil. Medium limestone also showed a significant increase over the untreated plot in the soil's exchangeable calcium. The hydrated lime and burnt lime gave the greatest increases of exchangeable calcium as might be predicted from the influence of the liming materials on the pH value of these soils. In general, very little difference in amounts of exchangeable calcium was shown by the various degrees of fineness of limestones.

The applications of liming material had no significant influence on the exchangeable magnesium as shown by a statistical analysis conducted over all soil types at the first sampling date. The only general increase of exchangeable magnesium seemed to be for the individual soils where heavy applications of dolomitic liming material were applied. Here slight increases were noticed on the Monmouth, Chester and Emory soil series. However, the data was not statistically analyzed for these three soils.

An overall statistical treatment for all soils investigated showed no significant decrease of exchangeable manganese with the liming treatments employed.

Potassium apparently was not uniformly affected by lime treatments. Although there were several cases in these results where the exchangeable potassium seemed to be either increased or decreased, there was no significant change of exchangeable potassium caused by any of the liming applications.

TABLE 35

Effect of Heavy Lime Treatments On Exchangeable Calcium for Mattapex, Matawan (Cordova), Monmouth, Chester, Duffield, and Emory Soil Series.

Soil Type	Treatment						
	Untreated	Coarse Limestone	Medium Limestone	Fine Limestone	Burnt Lime	Hydrated Lime	Average Value For Soil Type
	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm	m.e./100gm
Mattapex Silt Loam	2.61	5.80	3.34	2.61	5.81	6.56	4.46
Matawan Sandy Loam (Cordova)	2.53	2.50	3.07	2.92	2.95	2.48	2.74
Monmouth Loamy Sand	3.28	5.11	5.65	5.09	8.22	5.44	5.47
Chester Silt Loam	7.47	9.86	13.12	7.76	13.03	14.06	10.83
Duffield Silt Loam	7.37	9.07	9.28	9.21	9.00	8.77	8.78
Emory Silt Loam	7.59	7.66	8.43	8.05	8.03	6.99	7.80
Average Value For Treatment	5.14	6.67	7.15	5.95	7.85	7.38	

L.S.D. (Between Treatments) = 1.60

Persistence of Lime In Soil

At the beginning of this project, it was thought that the influence of the more soluble forms of lime would decrease in the soil within the three year experimental period. By examining Tables 15 and 17 which summarize the influence of lime on pH and Tables 23 and 25 which show the effect of lime on the exchangeable cations of sassafras and Monmouth soils, it can be seen that there are no indications of lack of maintenance ability by the more soluble hydrated or burnt forms of liming material during the period studied. The effect of all treatments on the pH, exchangeable hydrogen, calcium, and other cations of this investigation gave evidence that the greatest change occurred during the first few months after treatment. These data indicated that the liming influences remained fairly constant the two to four months and after three years the liming effects still persisted. However, this work has not been carried out over a sufficient length of time to give a final answer to the question of maintenance ability of lime materials in the soil.

Movement of Lime in the Soil

Sampling was not extensive enough to allow a statistical analysis of data on lime movement, but Tables 20, 24, 26 and 29 give some indication of the movement of lime into the subsoil. These results seem to indicate that there was some movement of lime into the subsoil because in general the heavy applications of lime produced a higher subsoil pH and more exchangeable calcium than occurred in the subsoils with light applications.

The lime movement was studied further on three of the farms by taking samples at regular depth intervals. These are summarized in Table 36. These results seem to indicate that the liming effects decreased

TABLE 36

Lime Movement As Indicated by the pH and Exchangeable Ions at Different Depths For Some Of The Soils And Treatments Studied.

Soil Type	Treatment: Rate in Tons Acre	Treatment: Kind of Lime	Time after Application	pH	H m.e./100gm.	Ca m.e./100gm	Mg m.e./100gm	Mn m.e./100gm
Sassafras silt loam								
Depths: 0-6 in.	0.00	Untreated	4 mos.	5.44	2.42	4.08	0.87	0.12
0-2 in.	2.85	Hydrated	4 mos.	6.97	0.00	6.48	0.91	0.03
2-4 in.				6.01	1.77	4.80	0.87	0.02
4-6 in.				6.05	1.61	4.76	0.97	0.09
6-8 in.				5.81	0.56	4.79	1.09	0.05
8-10 in.				5.76	1.87	4.15	1.45	0.03
0-4 in.	1.15	Fine	1 yr.	6.43	1.75	5.38	0.63	0.06
4-8 in.				6.06	2.49	4.35	0.72	0.08
8-12 in.				6.03	2.20	4.28	1.00	0.02
0-4 in.	3.65	Fine	1 yr.	6.66	0.96	5.13	0.58	0.06
4-8 in.				6.58	0.84	5.98	0.76	0.00
8-12 in.				6.38	2.04	5.34	1.19	0.03
Glenelg Loam								
Depths: 0-6 in.	0.00	Untreated	4 mos.	5.47	3.02	4.70	0.70	0.18
0-2 in.	3.50	Hydrated	4 mos.	6.69	0.00	10.70	1.35	0.14
2-4 in.				6.45	4.68	7.36	1.25	0.11
6-10 in.				5.53	4.85	3.57	0.95	0.06
Chester silt loam								
Depths: 0-6 in.	0.00	Untreated	4 mos.	5.80	6.13	7.47	0.90	0.09
0-2 in.	3.85	Hydrated	4 mos.	7.30	0.00	14.60	0.96	0.06
2-4 in.				7.25	0.00	14.88	0.70	0.04
4-6 in.				6.90	1.85	10.72	1.09	0.08
6-10 in.				6.40	4.32	7.20	1.09	0.06

regularly with the soil depth. However, lack of check plot data and pH measurements previous to lime applications make this data difficult to analyze.

Harvest Yields

Tables 37 through 45 give the crop yields as affected by the various lime treatments of the nine soils. Table 46 is a summary of the average relative yields of corn, wheat and hay for each crop season investigated, and Table 47 is a summary of the relative yields averaged for the three years of the study.

The three year average of the hay crop yields from limed soils was higher than the yields from the unlimed soils. The hay crops of the first year were limed by top dressing two months prior to harvesting. The results show that the hay plots which were harvested a year after liming gave the largest yield increases. This might support the practice of liming land a year ahead of the hay crop. These data also indicate that the hay plots cut two years after liming gave virtually the same yield as did the untreated plots. It should be emphasized that only one farm was in hay during this year, so the values for hay yields two-years after liming in Table 46 represent only that one farm (Sassafras silt loam). Examination of the results for pH values and exchangeable cations, as well as visual inspection of the field plots, gave no explanation for the apparent lack of response to lime in 1949.

Apparently wheat and corn yields are not appreciably affected by the forms or amounts of lime material used in this study, since only very slight increases were noticed. However, there was an appreciable increase of the wheat straw where the lime had been in contact with the

TABLE 37

Response of Wheat and Hay to Lime Treatments On Mattapex Silt Loam Soil. * (Princess Anne)

Treatment	Lime Applied Tons/Acre	Wheat (2 mos. after application)					Timothy-Clover ~~(1 yr. after application~~		
		pH	Straw		Grain		pH	Yield	
			Tons/Acre	Relative Value	Bu/Acre	Relative Value		Tons/Acre	Relative Value
Coarse Limestone	1.65	4.97	1.46	108	11.7	118	5.21	0.66	300
	4.35	5.80	1.40	104	10.6	107	5.82	0.57	259
Medium Limestone	1.70	5.45	1.19	88	9.3	94	5.20	0.60	273
	4.40	4.89	1.35	100	11.1	112	5.57	0.57	259
Fine Limestone	1.75	5.34	1.24	92	9.1	92	5.18	0.64	291
	4.80	4.97	1.35	100	9.9	100	5.37	0.65	296
Burnt Lime	1.15	5.38	1.34	99	8.0	81	5.56	0.78	354
	3.00	5.24	1.38	102	8.8	89	5.46	0.73	332
Hydrated Lime	1.20	5.27	1.48	109	9.9	99	5.22	0.59	268
	3.15	6.39	1.65	122	10.0	100	6.72	0.71	323
Untreated	0.00	4.64	1.35	100	9.9	100	5.00	0.22	100

* These plots were put into pasture in 1949; therefore, no yield data was obtained.

TABLE 38

Response of Hay and Corn To Lime Treatments On Matawan Sandy Loam Soil. (Salisbury)

Treatment	Lime Applied Tons/Acre	Clover (2 months after Application)			Corn (1 year after Application			Corn (2 years after Application)	
		pH	Tons/Acre	Relative Value	pH	Bu/Acre	Relative Value	Bu/Acre	Relative Value
Coarse lime-stone	0.62	6.58	0.70	140	6.18	22.4	127	31.5	85
	2.25	6.64	0.70	140	6.26	23.5	133	33.6	91
Medium lime-stone	0.62	6.76	0.70	140	6.25	32.6	185	32.4	88
	2.25	——	0.70	140	6.41	20.1	114	33.6	91
Fine lime-stone	0.62	6.84	0.60	120	6.20	25.6	145	33.2	90
	2.25	6.37	0.80	160	6.56	24.2	138	36.7	99
Burnt Lime	0.43	6.36	0.40	80	6.09	22.5	128	32.9	89
	1.55	——	0.80	160	6.40	28.8	164	34.4	93
Hydrated Lime	0.50	6.94	0.70	140	6.06	18.6	106	37.5	102
	1.80	7.05	0.70	140	6.51	22.0	125	38.3	104
Untreated	0.00	6.49	0.50	100	5.76	17.6	100	36.9	100

TABLE 39

Response of Corn and Wheat To Lime Treatments On Matawan Sandy Loam Soil. * (Cordova)

Treatment	Lime Applied Tons/Acre	Corn (4 months after Application) pH	Corn Bu/Acre	Corn Relative Value	Wheat (1 year after Application) Straw pH	Straw Tons/Acre	Straw Relative Value	Grain Bu/Acre	Grain Relative Value
Coarse limestone	0.85	5.74	71.5	103	6.02	1.16	114	9.8	82
	2.78	5.93	71.7	103	6.46	1.04	102	12.7	107
Medium limestone	0.85	5.76	72.5	105	6.16	1.23	120	10.9	92
	2.78	6.17	70.2	102	6.36	1.21	119	12.9	108
Fine limestone	0.85	5.94	66.7	96	6.40	1.78	174	12.5	105
	2.78	6.53	72.3	104	6.40	1.36	133	12.5	105
Burnt Lime	0.47	6.05	69.9	101	5.91	1.38	135	12.8	108
	1.71	6.52	77.6	111	6.85	1.44	141	14.8	124
Hydrated lime	0.67	6.15	70.3	102	6.24	1.47	144	15.1	127
	2.18	7.16	72.7	105	6.83	1.42	139	12.9	108
Untreated	0.00	5.75	69.2	100	5.90	1.02	100	11.9	100

* These plots were put into pasture in 1949 so no yield data was obtained.

TABLE 40

Response of Corn, Wheat and Hay to Lime Treatments on Sassafras Silt Loam Soil. (Chestertown)

Treatment	Lime Applied Tons/Acre	Corn (4 mos. after application)			Wheat (1 yr. after application)					Timothy-Clover (2 yrs. after application)		
						Straw		Grain				
		pH	Bu/ Acre	Relative Value	pH	Tons/ Acre	Relative Value	Bu/ Acre	Relative Value	pH	Tons/ Acre	Relative Value
Coarse Limestone	1.15	5.49	92.9	102	5.75	1.67	110	14.1	92	5.60	1.84	90
	3.65	6.00	92.9	102	6.56	1.54	101	13.8	90	5.95	2.33	114
Medium Limestone	1.15	5.90	91.0	100	6.09	1.66	109	16.2	106	5.70	2.20	108
	3.65	5.86	97.4	109	6.56	1.63	107	14.6	95	6.12	1.92	94
Fine Limestone	1.15	6.29	94.0	103	6.43	1.70	112	16.7	109	5.74	1.80	88
	3.65	6.81	90.5	99	6.66	1.60	105	17.5	114	6.60	2.09	102
Burnt Lime	0.70	6.25	89.2	98	6.21	1.57	103	14.4	94	5.50	1.83	90
	2.25	6.84	87.0	95	7.28	1.64	108	14.6	95	6.82	2.06	102
Hydrated Lime	0.95	6.06	97.2	106	6.72	1.63	107	14.3	93	5.60	1.86	91
	2.85	7.01	95.9	105	6.85	1.58	104	14.4	94	6.45	2.24	109
Untreated	0.00	5.44	91.3	100	5.75	1.52	100	15.3	100	5.05	2.04	100

TABLE 41

Response of Alfalfa to Lime Treatments on Monmouth Loamy Sand Soil. (Marlboro)

Treatment	Lime Applied Tons/Acre	Alfalfa* (1 Yr. after application)		
		pH	Tons/Acre	Relative Value
Coarse Limestone	1.47	5.75	2.86	109
	5.54	6.10	2.75	105
Medium Limestone	1.47	5.25	2.78	106
	5.54	5.85	2.93	112
Fine Limestone	1.47	5.65	2.62	100
	5.54	6.50	2.61	100
Burnt Lime	0.98	5.52	2.50	95
	3.50	6.80	3.15	120
Hydrated Lime	1.18	6.02	2.74	104
	4.38	7.00	3.05	116
Untreated	0.00	4.95	2.62	100

* Figures given represent the sum of two cuttings.

TABLE 42

Response of Corn and Wheat to Lime Treatments on Glenelg Loam Soil. * (Jarretsville)

Treatment	Lime Applied Tons/Acre	Corn (1 Yr. after application)			Wheat (2 yrs. after application			
					Straw		Grain	
		pH	Bu/Acre	Relative Value	Tons/Acre	Relative Value	Bu/Acre	Relative Value
Coarse Limestone	1.25	———	36.2	88	2.46	111	25.9	114
	4.90	———	44.7	109	2.39	107	26.2	115
Medium Limestone	1.25	5.95	40.4	98	2.51	113	25.8	113
	4.90	5.80	39.2	96	2.15	97	22.3	98
Fine Limestone	1.25	5.79	36.3	89	2.58	116	25.3	111
	4.90	6.21	45.7	111	2.70	121	31.6	139
Burnt Lime	0.88	5.81	38.4	94	2.54	114	25.4	112
	4.00	5.72	38.7	94	2.46	111	25.1	110
Hydrated Lime	1.00	5.77	37.7	92	2.50	113	26.5	117
	3.50	6.86	38.0	93	2.38	107	25.5	112
Untreated	0.00	5.90	41.0	100	2.22	100	22.7	100

* The crop yields of 1947 were mistakenly destroyed by the farmer.

TABLE 43

Response of Corn and Wheat to Lime Treatments on Chester Silt Loam Soil. (Sparks)

Treatment	Lime Applied Tons/ Acre	Corn (after 4 mos.) pH	Corn Bu/ Acre	Corn Relative Value	Wheat (after 1 year) pH	Wheat (after 1 year) Straw Tons/ Acre	Straw Relative Value	Grain Bu/ Acre	Grain Relative Value	Wheat (after 2 years) Straw Tons/ Acre	Straw Relative Value	Grain Bu/ Acre	Grain Relative Value
Coarse Limestone	0.68	6.05	57.9	94	6.49	2.54	102	19.7	74	3.47	108	34.9	117
	5.50	6.50	66.7	108	6.31	2.82	114	25.6	96	3.30	102	32.1	108
Medium Limestone	0.68	6.20	66.5	108	6.57	2.76	111	21.2	80	3.56	110	30.1	101
	4.55	7.40	68.0	110	7.49	2.66	107	27.6	104	3.32	103	31.6	106
Fine Limestone	0.68	6.40	62.0	101	6.51	2.76	111	24.2	91	3.62	112	36.2	121
	4.55	6.60	63.2	103	6.41	3.05	123	29.0	109	3.46	107	34.2	115
Burnt Lime	0.42	6.60	67.4	109	6.49	2.52	102	23.8	90	3.44	107	32.7	110
	2.75	6.98	65.5	106	7.01	3.01	121	28.6	108	3.45	107	34.3	115
Hydrated Lime	0.53	6.35	63.1	102	6.43	2.52	101	25.2	95	3.60	112	33.8	113
	3.35	7.37	64.6	102	7.38	3.14	127	27.5	104	3.68	114	33.1	111
Untreated	0.00	5.80	61.6	100	5.90	2.48	100	26.5	100	3.22	100	29.8	100

TABLE 44

Response of Hay and Barley to Lime Treatments on Duffield Silt Loam Soil. * (Frederick)

Treatment	Lime Applied Tons/Acre	Clover (after 2 months)			Barley (after 2 years)			
					Straw		Grain	
		pH	Tons/Acre	Relative Value	Tons/Acre	Relative Value	Bu/Acre	Relative Value
Coarse Limestone	3.95	7.60	1.18	83	1.87	111	25.4	114
Medium Limestone	3.95	7.30	1.18	83	1.74	103	23.7	107
Fine Limestone	3.95	7.30	1.18	83	1.88	111	23.2	104
Burnt Lime	2.40	7.10	1.18	83	1.63	97	20.3	91
Hydrated Lime	3.05	7.40	1.38	96	1.25	74	17.2	77
Untreated	0.00	6.60	1.43	100	1.68	100	22.2	100

* The crop yields of 1948 were mistakenly destroyed by the farmer.

TABLE 45

Response of Hay, Corn, and Wheat to Lime Treatments on Emory Silt Loam Soil. (Hagerstown)

Treatment	Lime Applied	Hay (after 2 mos.)			Corn (after 1 yr.)			Wheat (after 2 yrs.)			
								Straw		Grain	
	Tons/Acre	pH	Tons/Acre	Relative Value	pH	Bu/Acre	Relative Value	Tons/Acre	Relative Value	Tons/Acre	Relative Value
Coarse Lime-stone	4.05	6.79	0.82	91	7.10	21.2	83	1.68	69	16.0	75
Medium Lime-stone	4.15	7.00	0.98	109	7.10	34.1	133	2.42	99	20.7	97
Fine Limestone	4.45	6.81	0.69	77	7.08	38.9	152	2.64	108	23.4	109
Burnt Lime	2.30	7.56	0.86	96	7.63	43.7	171	2.25	92	21.3	99
Hydrated Lime	2.95	7.69	0.90	100	6.79	44.9	175	2.73	111	24.4	114
Untreated	0.00	6.70	0.90	100	6.77	25.6	100	2.45	100	21.4	100

TABLE 46

The Relative Effect on Hay, Wheat and Corn by Lime Treatments as Composited for All Farms.

Treatment	Relative Amount Applied	Average Relative Values											
		Hay			Wheat						Corn		
					Straw			Grain					
		after 2 mos	after 1 yr.	after* 2 yrs.	2 mos.	1 yr.	2 yrs.	2 mos.	1 yr.	2 yrs.	4 mos.	1 yr.	2 yrs.
Coarse Limestone	Light	140	300	90	108	109	109	118	83	115	100	108	85
	Heavy	105	259	114	104	106	93	107	98	99	104	108	91
Medium Limestone	Light	140	273	108	88	113	111	94	93	107	104	141	88
	Heavy	110	259	94	100	111	100	112	102	100	106	114	91
Fine Limestone	Light	120	291	88	92	132	114	92	102	116	100	117	90
	Heavy	106	296	102	100	120	112	106	109	121	102	134	99
Burnt Lime	Light	80	354	90	99	113	110	81	97	111	103	111	89
	Heavy	113	332	102	102	123	103	89	109	108	104	143	93
Hydrated Lime	Light	140	268	91	109	117	112	100	105	115	103	94	102
	Heavy	112	323	109	122	123	111	100	102	112	105	131	104
Untreated		100	100	100	100	100	100	100	100	100	100	100	100

* Values represent only one farm (Sassafras silt loam) for this year.

TABLE 47

Relative Effect of Liming Materials on Hay, Wheat, and Corn for the Combined Years of 1947, 1948 and 1949.

Treatment	Relative Values							
	Hay		Wheat				Corn	
	Light Rate	Heavy Rate	Straw		Grain		Light Rate	Heavy Rate
			Light Rate	Heavy Rate	Light Rate	Heavy Rate		
Coarse Limestone	177	137	109	100	99	101	100	104
Medium Limestone	173	137	108	104	98	103	114	108
Fine Limestone	166	143	119	113	106	112	104	115
Burnt Lime	175	154	110	110	99	104	103	119
Hydrated Lime	166	154	114	112	107	102	102	116
Untreated	100	100	100	100	100	100	100	100

soil a year before harvesting. There was no trend in the results indicating a superiority of any one form of liming material over that of another in its influence upon crop yields.

A Suggested Lime Recommendation Method

A rapid and reasonably accurate method of making lime recommendations can be based on pH measurements if agreement between the relationship of pH to percentage hydrogen-saturation can be shown for the soils of the state. Figure 10 is a graph of pH values plotted against the corresponding percentage hydrogen-saturation as determined for the nine soils in this study. In order to check the agreement of this relationship further, pH values and exchangeable hydrogen data of another project were included for 24 important soils of the state. Four of these soils were from farms used in this present liming investigation. Figure 11 gives this data, and Table 48 shows the location and soil types presented by Figure 11. It should be emphasized that this data was obtained from an independent research project and the analyses presented were performed by different workers. The soils studied were of statewide locations, giving a good general picture of Maryland soils.

Pierre and Scarseth have shown that there was general agreement between the pH value of a given soil and its corresponding percentage base saturation. It was felt that this relationship might hold in general for the majority of the soils in Maryland. Figure 10 shows that general agreement of pH value versus the corresponding percentage hydrogen saturation does hold for the nine soils studied. Application of the data of Thomas, et al. (57) and Thomas and Winant (58) further substantiates this general agreement of pH versus percentage hydrogen saturation for 24 Maryland soils investigated. Thus from this relationship one could predict

Figure 10

Relation Between pH and the Percentage Hydrogen-Saturation of Nine Maryland Soils

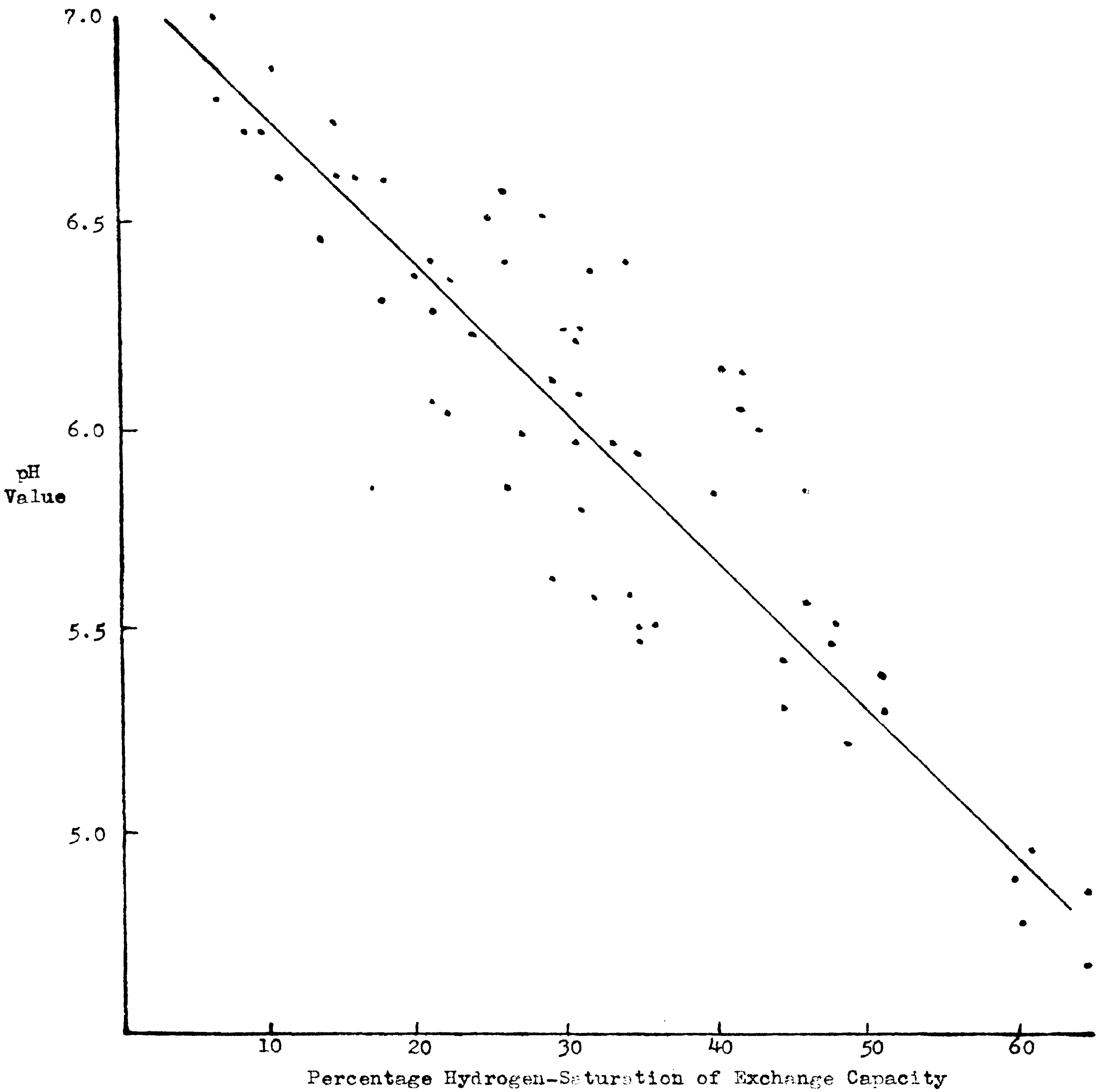


Figure 11

Relation Between pH and the Percentage Hydrogen-Saturation of Soils From Thirty-four Locations, Involving Twenty-four Maryland Soils Types

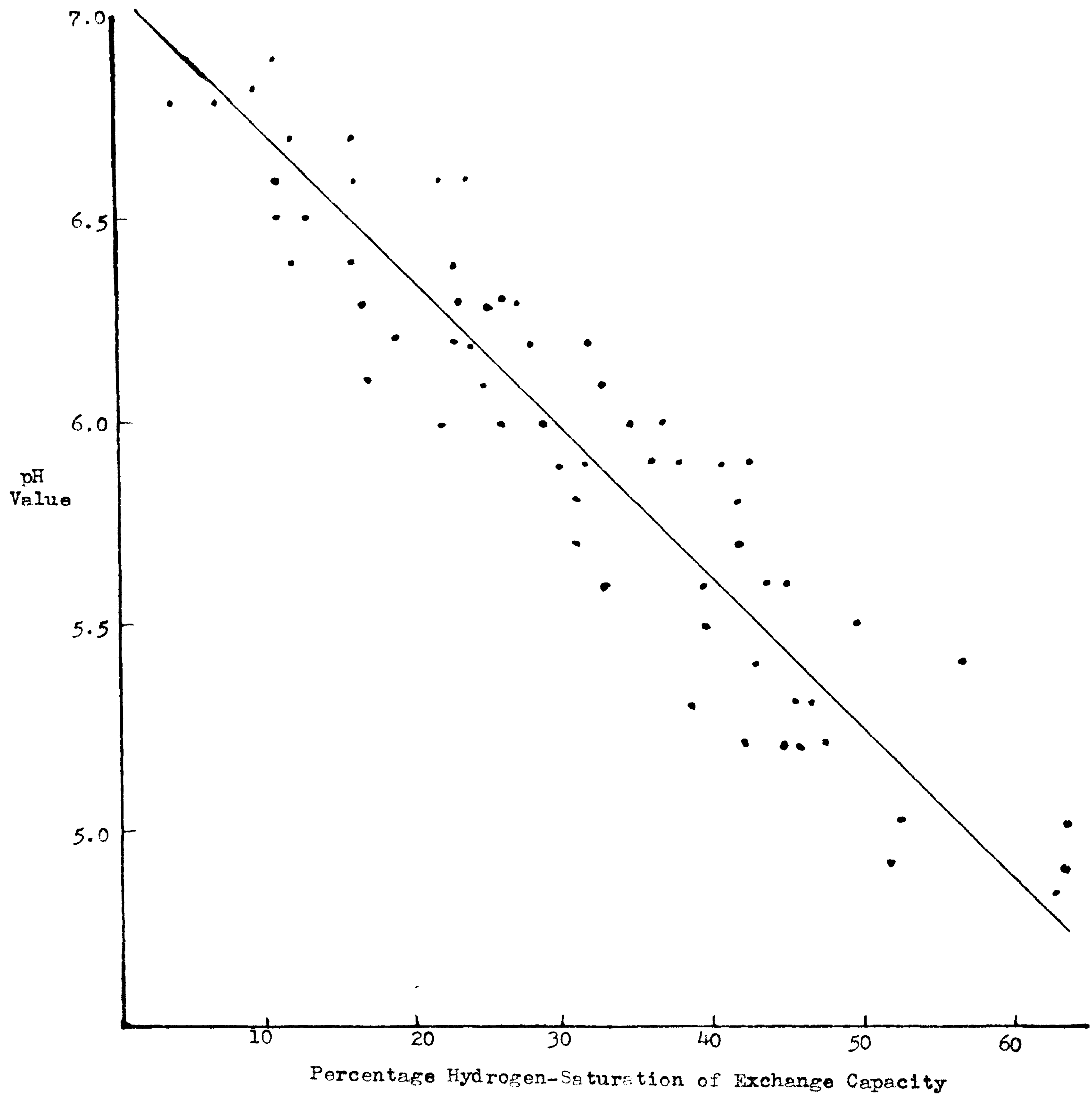


TABLE 48

The State-wide Distribution of the Soil Types Whose Analyses are Presented in Figure 11.

LOCATION		SOIL TYPE
TOWN	COUNTY	
Salisbury	Wicomico	Matawan sandy loam
Chestertown	Kent	Sassafras silt loam
Chestertown	Kent	Butlertown silt loam
Chestertown	Kent	Sassafras silt loam
Hagerstown	Washington	Hagerstown silt loam
Hagerstown	Washington	Emory silt loam
Boonsboro	Washington	Duffield silt loam
BelAir	Harford	Chester loam
BelAir	Harford	Glenelg loam
Sparks	Baltimore	Glenville loam
Sparks	Baltimore	Manor loam
Manchester	Carroll	Manor gravelly loam
Centerville	Queen Anne	Butlertown silt loam
Churchville	Harford	Glenelg loam
Churchville	Harford	Chester loam
Churchville	Harford	Neshaminy silt loam
Ridgely	Caroline	Fallsington sandy loam
Ridgely	Caroline	Elkton loam
Ridgely	Caroline	Sassafras sandy loam
Frederick	Frederick	Duffield silt loam
Frederick	Frederick	Hagerstown stoney loam
Frederick	Frederick	Wiltshire silt loam
Frederick	Frederick	Duffield silt loam
Mt. Airy	Carroll	Manor slate loam
Mt. Airy	Carroll	Glenelg loam
Darnestown	Montgomery	Glenelg loam
Darnestown	Montgomery	Manor loam
Sparks	Baltimore	Manor loam
Sparks	Baltimore	Glenelg loam
Colesville	Montgomery	Elioak loam
Jarretsville	Harford	Glenelg loam
Wye Mills	Queen Anne	Galts silt loam
Princess Anne	Somerset	Mattapex silt loam
Burtonsville	Montgomery	Elioak loam

the percentage hydrogen saturation of the exchange complex from the pH value.

A rapid estimation of lime requirements is proposed from this relationship which is applicable to the soils studied. Figure 12 is a general graph of pH plotted against the percentage hydrogen saturation as drawn for the soils used in both this project and the research of Thomas, et al. Now with only a pH measurement and this graph, the approximate percentage of hydrogen saturation of a Maryland soil can be determined. Thus, if the total exchange capacity of a soil is known then the amount of exchangeable hydrogen can be easily determined from a multiplication of the percentage hydrogen saturation by the total exchange capacity. This total exchange capacity can be estimated accurately enough by an experienced worker who is familiar with the Maryland soils. Since lime recommendations are always given in very general terms, this estimation of the total exchange capacity should not introduce an effective error. Once the amount of exchangeable hydrogen is known, it is simple to determine the quantity of lime material necessary to reduce this exchangeable-hydrogen to that which is present at the desired pH value.

As an example a Chester silt loam, which has an exchange capacity of 10 milliequivalents, might be taken. If its pH value is 6.0, Figure 12 would indicate that 30 percent of its exchange capacity, or (30% x 10 m.e.= 3.0 m.e.), is saturated with hydrogen. At a desired pH of 6.5, Figure 12 indicates that 15 percent, or 1.5 m.e., of the exchange capacity is saturated with hydrogen. This means enough lime must be added to replace 1.5 milliequivalents of hydrogen (3.0 m.e. - 1.5 m.e. = 1.5 m.e.) to raise the soil pH from a value of 6.0 to 6.5. Table 49 shows that approximately two milliequivalents of the liming materials used in this experiment were required to replace one milliequivalent of exchangeable hydrogen on the

Figure 12

A General Plot of pH Against Percentage Hydrogen-Saturation Applicable to Maryland Soils

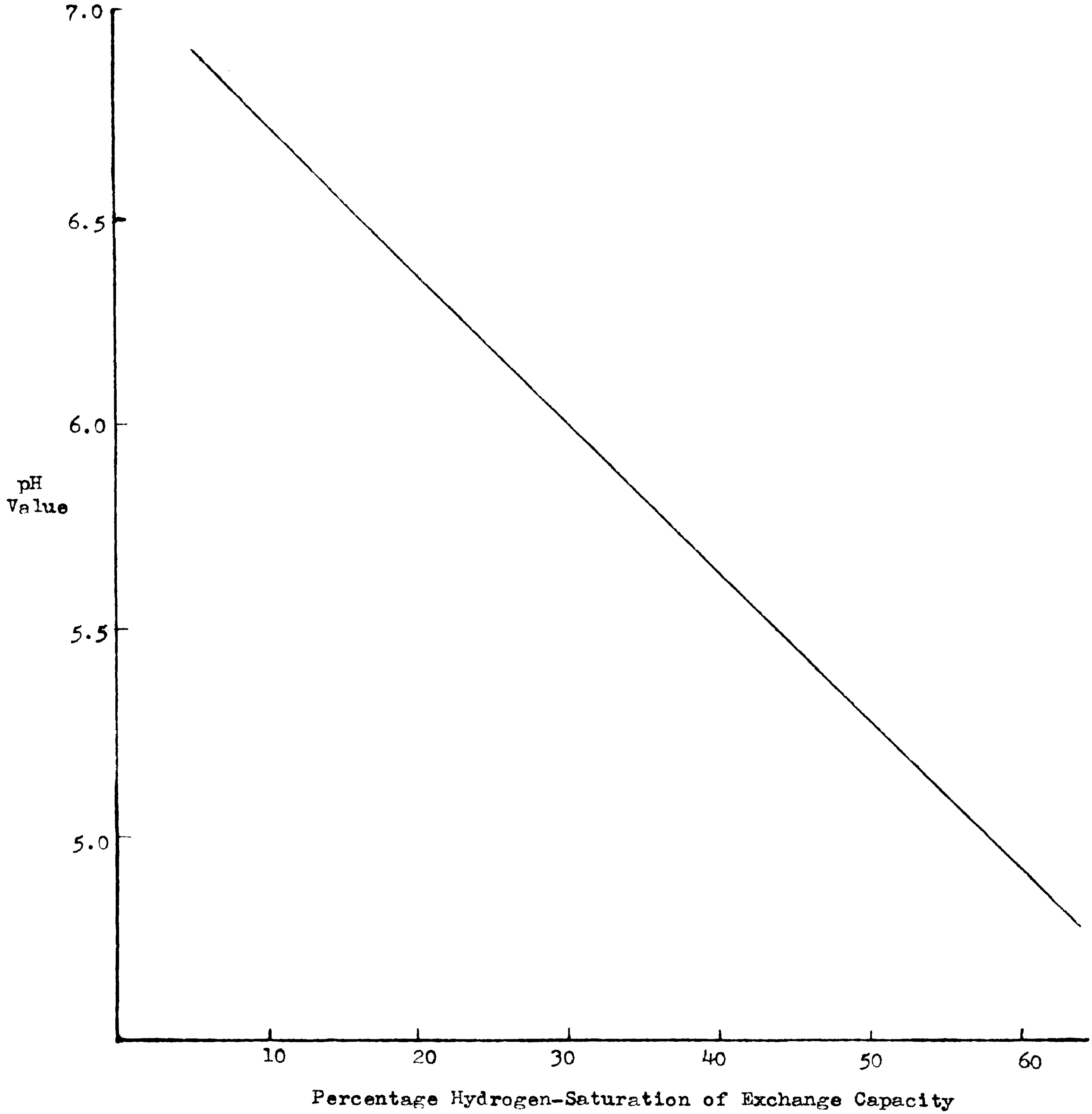


TABLE 49

Estimated Milliequivalents of Liming Materials Required to Replace 1 Milliequivalanet of Exchangeable Hydrogen for Some Acid Maryland Soils

Soil Types	Limestone		Burnt Lime		Hydrated Lime	
	M.E. Added for Combined Limestone Treatment	M.E. H Replaced by This Limestone	M.E. Burnt Lime Added	M.E. H Replaced by Burnt Lime	M.E. Hydrated Lime Added	M.E. H Replaced by Hydrated Lime
Mattapex Silt Loam	9.75	3.99	11.87	5.95	11.87	5.93
Matawan Sandy Loam (Salisbury)	3.63	1.74	1.21	0.33	1.21	0.87
Matawan Sandy Loam (Cordova)	1.71	0.33	1.71	0.57	5.56	1.67
Sassafras Silt Loam	2.24	1.07	2.24	1.52	2.24	1.26
Monmouth Loamy Sand	5.88	3.21	2.94	1.49	2.94	1.77
Chester Silt Loam	4.08	3.39	9.10	5.00	10.46	9.80
Estimated m.e. Liming Material to Replace m.e. H	1.99	1.00	1.96	1.00	1.60	1.00

General overall estimate for all liming materials necessary to replace 1.0 m.e. of exchangeable hydrogen = 2.0 m.e.

exchange complex of the acid soils studied. Therefore, if ground limestone is used on this Chester silt loam then three milliequivalents of the limestone should be applied, i.e., 1.5 m.e. of exchangeable hydrogen to be replaced multiplied by the 2 m.e. of limestone that is needed to replace each m.e. of exchangeable hydrogen (1.5 m.e. x 2 = 3.0 m.e.). Since one milliequivalent of limestone per one acre is equivalent to 1000 pounds this soil would require 3000 pounds per acre, (3.0 m.e. x 1000 lbs. = 3000 lbs.) One milliequivalent of burnt lime is equivalent to 560 pounds per acre so that 1680 pounds are needed for this soil and since one milliequivalent of hydrated lime is equivalent to 740 pounds per acre then 2220 pounds of liming material are required.

DISCUSSION

This investigation has shown that all the lime treatments employed increased the soil pH significantly above the pH value of the untreated plots. However, in general, there were only a few differences shown between the various lime materials in their influence on soil pH, exchangeable cations, or crop yields. Most of these differences when they did occur, were small and probably of little practical agronomic importance. The hydrated lime treatments, although they were not significantly different from other lime treatments in all uses, showed a trend of greater influence on soil pH and exchangeable cations than the limestone forms. The reason for this trend of the hydrated form is probably twofold: the hydrated lime was more soluble than the carbonate form and its extremely fine state of division was thought to give it a larger effective surface area.

Since these results have shown such small differences between the different grades of limestones used, it is indicated that it might not always be necessary to grind limestone too fine. If a limestone which is ground to pass a 40-mesh sieve contains enough fine material to give approximately the same immediate soil pH effect as that which is ground to pass a 100-mesh sieve, then this coarser material might be superior since it is thought to persist in the soil over a longer period. Since the limestones used in this experiment were not from the same source it is possible that there was a difference in the solubility of these materials. The results suggest that further experimental work should be conducted on the influence of differentially ground limestones on soils.

Since only small differences were shown between the various lime materials in their effect on the soil and crops, these results indicate that the prime consideration of a farmer in choosing a liming material should be the cost. The farmers in sections far-removed from natural sources of lime are highly affected by transportation rates, thus making it economically feasible in such sections to use the hydrated or burnt forms of lime. However, when lime materials are applied for crops demanding a high pH value and quick results are desired then hydrated lime would probably be the most ideal for this quick effect.

A study of the pH values and the exchangeable hydrogen figures indicates that much more liming material was needed than the amount calculated by the lime requirement method employed. This was because the exact equivalents of calcium and magnesium were added to saturate the exchange complex by 80 or 160 percent and this calculated amount was on the basis of complete solubility and 100% absorption by the clay particles. Since the solubility of all lime materials is comparatively slow, they did not go into solution rapidly enough to affect the calculated change over the period of time studied.

The new lime recommendation method which is proposed includes an empirical factor which should bring the pH value up to any desired level. The chief advantage of this proposed method is that it is rapid, accurate, and suitable to the soil testing laboratory. It requires only a pH determination and two very short and simple calculations. The pH measurement can be made on small amounts of soil and no chemicals or laboratory equipment other than a standard pH meter are necessary. This method would function for the majority of the soils of the state. However, a few soils which have an unusually high organic matter content or a widely different type of mineral composition probably would not have the same pH-percentage hydrogen saturation relationship presented in Figure 12. The estimates of total exchange capacity of a soil and amount of lime to replace one milliequivalent of exchangeable hydrogen are approximate values. However, reasonably accurate results would be expected for estimating lime requirements of Maryland soils. It is believed that this field calibrated method is superior to the more general figures used in Maryland and many states.

SUMMARY AND CONCLUSIONS

Liming investigations were conducted on nine important Maryland soils. The liming materials examined were limestone, burnt lime, and hydrated lime. In turn, the limestone was added in three different states of division, a coarse, medium, and fine ground limestone. The nine soils chosen for this experiment were located in prominent agricultural areas throughout the state and represent diversified soil conditions.

The general conclusions reached for all soils studied in this experiment can be briefly stated as follows:

1. The pH value of surface soil was significantly increased by all additions of lime materials.
2. The hydrated form of lime gave the greatest effect on the soil reaction. The different grades of fineness of limestone in the heavier applications used in this investigation did not give significant differences to soil pH. However, there was a significant increase in pH values of soils treated with light applications of fine limestone when compared with soils treated with coarse and medium limestones.
3. An increase in the quantity of liming material added to the soil produced a larger increase in soil pH.
4. The greatest change in soil reaction occurred during the first two to four months after treatment.
5. Liming resulted in a decrease of exchangeable hydrogen in the soils treated with both light and heavy applications of lime when compared with untreated plots. Only slight differences were found between the various liming materials used in this experiment in their ability to reduce exchangeable hydrogen in the soil when these materials were added in chemically equivalent amounts.

However, the soils treated with hydrated and burnt lime seemed to give the greatest decreases in exchangeable hydrogen.

6. The data indicated that approximately two milliequivalents of the liming materials used were required to replace one milliequivalent of exchangeable hydrogen.

7. Soils treated with heavy applications of lime showed a significant increase in exchangeable calcium above the values of the untreated soil.

8. Neither exchangeable potassium nor exchangeable magnesium was significantly changed by the liming treatments.

9. The data for all the soil types showed no significant change in exchangeable manganese with the liming treatments employed. However, the Mattapex silt loam, Sassafras silt loam, Monmouth loamy sand, and Chester silt loam seemed to decrease in exchangeable manganese upon liming.

10. The ability of the limestones, burnt lime, and hydrated lime to persist in the soils over a three-year period was relatively constant as indicated by little or no change of pH and exchangeable cations. The more soluble hydrated lime persisted in the soil as well as the more insoluble limestones over the three year period.

11. There was some downward movement of the liming materials as indicated by the pH values of the subsoil.

12. The hay yields of this experiment were generally increased by liming. However, no individual lime material gave appreciable increases over the other materials. No generally increased yields were observed for wheat or corn.

13. A direct relationship between the pH and percentage hydrogen saturation was shown to exist for a large group of Maryland soils.

14. By use of this pH and percentage hydrogen saturation relationship, a rapid and an improved method of estimating the lime needs of Maryland soils was proposed.

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