

THE EFFECT OF CERTAIN LIMING PRACTICES UPON THE
CHEMICAL COMPOSITION AND PROPERTIES OF
SEVERAL MICHIGAN SOILS

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ABSTRACT

Field studies were conducted on three soils to compare the effect of liming materials varying in composition, neutralizing value, and degree of fineness on the rate of change of soil reaction, content of exchangeable bases, and the percent base saturation. In addition, the chemical availability of phosphorus and potassium and the yields of the crops grown on the experimental areas were used as criteria in assessing the relative merits of the various liming materials.

Similar studies were carried out with five soils in the greenhouse. Equivalent amounts of three liming materials were applied in quantities equal to the lime requirement. Samples of alfalfa, the indicator crop, were analyzed for phosphorus to determine the effect of lime on the content and uptake of this element. Soil samples were taken at two-month intervals to measure changes in soil reaction resulting from the application of the three liming materials. Available phosphorus and potassium were determined on soil samples taken following the last harvest of alfalfa.

Lime requirement showed a relatively high degree of correlation with the hydrogen-ion concentration and the percent base saturation prior to liming, especially on the poorly buffered Kalkaska sand.

However, applying lime to field soils as a fractional part of the total lime requirement in order to reach a desired pH level did not prove to be an accurate method. Although in the field, lime applications did not raise the pH to the values expected by laboratory tests, applications of lime equal to the lime requirement under greenhouse conditions exceeded the theoretical values.

One year after the application of lime the differences in pH, percent base saturation, and total exchangeable bases resulting from the use of comparable rates of the various materials were very slight. Significant correlation existed between changes in the hydrogen-ion concentration and changes in the content of exchangeable bases and the percent base saturation for any one soil.

Calcitic limestone meal increased the pH more rapidly than did dolomitic meal of comparable fineness. Pulverized dolomitic limestone increased the pH more quickly than any of the materials studied, while water-quenched calcium silicate slag was the least reactive material used.

Yields of sweet clover were significantly increased by the higher rates of application of lime to the Kalkaska sand, especially where the pulverized dolomitic limestone was used. Lime had no appreciable effect upon the yields of wheat, corn, and oats grown on the Warsaw loam and Hillsdale sandy loam soils.

In the greenhouse, the total yield of alfalfa was significantly increased by additions of calcium carbonate and pulverized dolomitic limestone to the Hillsdale sandy loam, and by additions of the dolomitic lime and calcium silicate slag to the Kalkaska sand. No significant changes in the total yield of alfalfa occurred as a result of liming the Brookston clay loam, Fox sandy loam, and Warsaw loam soils.

In the field there was no significant correlation between changes in the hydrogen-ion concentration after liming and changes in the chemical availability of phosphorus and potassium. Lime tended to slightly lower the level of phosphorus in the greenhouse soils.

The phosphorus content and total uptake of phosphorus by alfalfa was increased by liming, particularly with calcium carbonate and pulverized dolomitic limestone.

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INTRODUCTION

Lime, in its various forms, has been used throughout the world for the correction of soil acidity for many centuries. However, since the beginning of the twentieth century its use has steadily increased, especially in regions of relatively abundant rainfall and consequently rapid leaching.

The value of lime as a soil amendment and its effect upon many chemical, physical, and biological processes in the soil has been established, at least in a general way. Because of these many and varied effects upon the soil and the plants which grow on it, it becomes especially desirable to obtain a clear understanding of any changes which result from the use of different liming materials when applied to divergent types of soil, as well as to ascertain whether or not present liming practices are adequate to give maximum crop yield and quality.

With an increase in the use of lime by Michigan farmers many new liming materials have been offered for sale throughout the state. One of the primary aims of this investigation was to compare some of these liming materials varying in composition, fineness, and neutralizing value. The main criterion for comparison was the rate

of change of soil reaction as measured by pH, total exchangeable bases, and percent base saturation.

It has been pointed out on numerous occasions that because of differences in the clay and organic matter content of soils, liming recommendations based upon pH alone may give quite erroneous and misleading results. The fact remains, however, that the determination of soil reaction is one of the easiest and most informative soil tests yet devised. It is still widely used as a criterion for assessing lime needs. To study some of these variations, soils were selected which offered a considerable range in clay and organic matter contents.

A great deal of research work has been conducted on the effect of lime on the availability of phosphorus and potassium in the soil. Although general trends in availability have been established, conflicting evidence is present and differences of opinion do exist. As a supplementary phase of this study, phosphorus and potassium determinations were made on all field and greenhouse samples to show any changes which took place in the chemical availability of these two elements as the pH and percent base saturation increased due to liming.

REVIEW OF LITERATURE

If the value of an agricultural practice can be determined by its age and widespread usage, then that of liming soils must rank as one of the most firmly established practices in the humid temperate regions of the world. Truog (65) has commented that liming of the soil was practiced before the Christian era, but lagged in this country for many years due to the lack of scientific knowledge and satisfactory methods to determine the actual needs and the proper use of lime. He credits Edmund Ruffin (1794-1865), a practical Virginian farmer, with being the first man in the United States to recognize the prevalence of soil acidity and conduct liming experiments. In assessing the value of liming, Truog has stated that "it [liming] must be the very backbone of profitable crop production, soil conservation and permanent agriculture in the humid regions of this country."

The actual benefits derived from liming acid soils have long been the subject of intensive investigation and debate. Some workers (1, 47) have suggested that much of the deleterious effect of acid soils upon plant growth is due to a lack of sufficient exchangeable calcium. Others have stated that this reduced growth on acid soils is due either to the direct injurious effect of the hydrogen ion on plant roots

(26) or to a combination of factors, including the influence of lime on the availability, uptake, and/or reduction in toxicity of other elements (5, 32, 49, 53, 61). Arnon and Johnson (4), using careful studies with nutrient solutions and sand cultures, have shown that many plant species can make normal growth at pH values as low as those encountered in most acid soils, provided adequate calcium is supplied.

Peech (49) included the direct nutritional value of calcium and magnesium, the improvement of soil physical condition, the stimulation of microbial activity, the neutralization of hydrogen ions, and the influence on the fixation, toxicity, and leaching of many nutrient elements among the primary benefits of liming. Kelley (32), in a comprehensive review, considered calcium to be of greater fundamental importance than nitrogen, phosphorus, and potassium in the soil, while Truog (66) has related soil acidity and liming to the availability of the majority of the plant nutrients in the soil.

Numerous methods have been devised to determine the amount of lime to apply to correct an acid soil condition. Peech and Bradfield (52) have divided lime requirement methods into several groups depending upon the technique employed. These are: (a) determination of exchangeable hydrogen; (b) rapid determination of the lime requirement; (c) determination of soil reaction; (d) determination of

exchangeable calcium and degree of calcium saturation; and (e) determination of readily soluble aluminum, iron, and manganese. The authors have pointed out some of the advantages and limitations of these various methods.

Of the methods now in use for determining lime needs, those involving rapid determination of the exchangeable hydrogen are perhaps most common. The term "lime requirement" has been used to denote the amount of lime that must be applied to the soil to bring the reaction to neutral or some desired pH. Some of these rapid lime requirement methods have made use of calcium hydroxide titrations (22, 23, 65), while others are based on a single extraction of exchangeable hydrogen with some salt solution and subsequent titration of this extract with a standard base solution (12, 15, 30). Shimp (62), from his studies on several Michigan soils, concluded that the determination of exchangeable hydrogen was the best known method for determining lime requirement, since it correlated more closely with the lime requirement when compared to other chemical properties studied.

Of the chemical methods for estimating the lime needs of soils, the soil reaction test is by far the simplest and most commonly employed. Peech and Bradfield (52) stated that "quite aside from ecological significance, the simple test for soil reaction affords

the most useful single value characteristic for estimating the lime needs of soils.'" They further suggested that the use of a 1:1 soil-water ratio appeared to be the best for routine soil reaction determinations.

Bray and DeTurk (13) cautioned against the use of hydrogen ion concentration as a measure of lime requirement due to differences in soils with respect to base exchange capacity. They found poor correlation between pH and degree of base saturation in soils less than 60 percent base saturated. Others (41) have pointed to the unreliability of the pH-percent base saturation relationship existing in soils of varying type.

Mehlich (40) showed that the base unsaturation-pH relationship is a specific expression of the base exchange mineral present and is therefore not influenced by exchange capacity or buffer activity. He concluded that in order to determine lime needs it is only necessary to measure the base exchange capacity and pH or base exchange capacity and base unsaturation. It has been shown for several Michigan soils (62) that pH alone does not give an accurate liming value for soils of widely varying textures and exchange capacities. Furthermore, the pH-percent base saturation relationship is too imperfect to use as a single factor in lime requirement determinations.

Peech and Bradfield (52) have summarized their discussion on lime requirement determinations by stating that "not until the causes of the poor growth of plants on acid soils and the nature of the response of crops to liming are thoroughly understood, will it be possible to evaluate properly the relative usefulness of the different chemical methods that have been proposed for the estimation of the lime needs of soils."

The fact that response to liming depends to a certain extent on the nature of the clay minerals in the soil has been recognized by several investigators. Marshall (38), studying complete titration curves of montmorillonite and kaolinite with calcium hydroxide, showed that with additions up to 70 percent saturation, conditions for uptake by plants from montmorillonite did not materially improve. In the case of kaolinite, a gradual transition was found in the release of calcium with increasing saturation. This was explained by the fact that below 70 percent saturation, montmorillonitic clays have a higher energy of adsorption for the calcium ion, while kaolinite releases calcium with equal ease irrespective of the degree of saturation. Reed and Cummings (57) pointed out that in soils with colloids of the 2:1 type, a higher degree of calcium saturation and a higher calcium level are required for good growth than is necessary for

soils of the 1:1 type colloid. They also found a need for considerably higher lime levels on soils high in organic matter.

Miles (43) showed that with a low exchange capacity, relatively small amounts of calcium are required to effect the desired degree of saturation. On several poorly buffered North Carolina soils, the degree of saturation required for most general crops was found to be between 40 and 60 percent for soils of the kaolinitic type.

The rate of application of liming materials to the soil with respect to the desired level of calcium saturation and pH has been the subject of considerable research. Truog (65) originally suggested that sufficient lime should be added to bring the soil reaction to a pH of from 6.5 to 7.0. Others (56) have suggested a similar soil reaction depending upon the crops being grown. Bear and Toth (9) proposed a level of 65 percent calcium saturation as being ideal for the majority of soils, while Bray and DeTurk (13) felt it was not advisable to maintain a degree of base saturation over 80 percent due to the extra leaching above this point. Lipman et al. (34) indicated that it was not necessary to fully satisfy the lime requirement of the soil in order to obtain good results.

It is known that the source, composition, and fineness of the liming material exerts a strong influence on the rate of change of soil reaction and over-all crop response. Calcitic and dolomitic

limestones have largely replaced some of the older materials such as hydrated lime. However, many refuse and by-product liming materials are now being offered for sale.

Davis (19) reported that dolomitic limestone produced the highest yields of crimson clover while calcitic limestone gave the highest yields of Sudan grass. However, he found that the high calcium lime raised the pH of the soil more than the corresponding grade of dolomitic stone. Lipman and his associates (34) showed that liming increased crop yields, especially legumes, with only a slight difference in favor of the dolomitic limestone. Morgan and Salter (46) found a slower rate of reaction for dolomitic materials when compared with high calcium carbonates, while Naftel (48), using six crops in a greenhouse study, obtained a greater response from a mixed calcium and magnesium lime than from calcium lime alone, especially on lighter soils. Millar and Grantham (45) concluded that any of the grades of ground limestone which they used in their experiments were more economical sources of lime than the hydrated lime. Schollenberger (60) found that natural dolomite was 50 percent less reactant than the high calcium materials studied, while basic slag was the least reactive material tested.

Perhaps more important than the basic composition of the liming material in determining the rate of change of soil reaction is

the degree of fineness. Albrecht and Smith (2) found a substantial increase in the growth of sweet clover seeded with oats when 300 pounds of 10-mesh lime per acre was drilled in at time of seeding. They suggested that a few foci of less soluble limestone in a soil volume, reacting slowly with the clay, are more effective in providing the plant with calcium than the more soluble forms reacting rapidly with the clay. However, Bray and DeTurk (13) noted that over a five-year period, limestone screenings were only 75 to 80 percent as effective as finely pulverized limestones. In pot tests with sweet clover more than twice as much 8- to 10-mesh limestone was required for good growth as 100-mesh limestone. Davis (19) obtained highest yields of crimson clover and Sudan grass over a seven-year period using 60- to 100-mesh limestone. He recommended that 100 percent of the lime should pass a 10-mesh screen and 50 percent should pass a 60-mesh screen.

Morgan and Salter (46) stated that the fineness to which dolomitic limestones are ground is of greater relative importance than is the case with high calcium limestones. However, they felt that with a dolomitic limestone containing considerable 100-mesh material, the rate of solubility would be sufficiently rapid for all practical purposes. MacIntire et al. (35) found that there was little difference between the availability of ground limestone, ground dolomite, and

hydrated lime, when the limestones were between 100 and 200 mesh. Webster and co-workers (68) noted that potassium permanganate titration values were influenced by actual surface area exposed and the Mg:Ca ratios of twenty-eight samples of agricultural limestone meals. Measurements made on equivalent-sized particles of calcitic and dolomitic limes showed that the calcium stones had a faster rate of dissolution in hydrogen-saturated clay suspensions.

Early experiments in Michigan (39) showed that hydrated lime and limestone finer than 80-mesh gave superior yields of rye than marl, 40- to 60-mesh, or 10- to 20-mesh limestone. Later recommendations (44) called for limestone ground so that "practically all will pass a 10-mesh screen and at least one-third will pass an 80-mesh screen."

Beacher et al (8) reported that coarse dolomitic limestone was less soluble and less effective in promoting growth of crimson clover than a calcium stone of equal size. It was also less effective in raising the pH and lowering the content of hydrogen, aluminum, and manganese in the soil. On six Maryland soils (28), increasing the quantity of liming material added to the soil increased the pH value more than did a greater degree of fineness, while another study (42) indicated that in order for agricultural limestone grades to be effective during

the first year after application, a large portion of it must be finer than 40-mesh.

Numerous other investigators (16, 18, 31) have recognized the need for liming materials of sufficient fineness to meet immediate needs, yet coarse enough to exert an influence over a period of several years. Particular attention should be given to the degree of fineness where immediate or first-year results are desired (56).

Of the many phases of soil acidity and liming which have been studied, perhaps none has been more thoroughly investigated than the effect which these conditions exert upon the availability of native and added plant nutrients. Foremost in this regard have been the studies on phosphorus. Beater (10) has reported that increasing the pH to certain specified levels by lime additions prior to planting resulted in a 20 percent increase in the concentration of phosphates in the dry material of plants studied, while Davis and Brewer (20) found that a deficiency of calcium limited the normal uptake of phosphorus by plants growing on four Louisiana soils.

Results obtained by Salter and Barnes (58) on eleven crops grown in the field indicated that the lack of response to superphosphate under slightly neutral conditions created by liming was largely due to the fact that the lime had increased the availability of the native soil phosphorus so that the plants required no additional

phosphorus in the form of fertilizer. Toth and Bear (64) found that as calcium was introduced into the exchange complex, the phosphorus adsorbing power decreased on these limed soils. They suggested that the exchangeable calcium was functioning primarily to adsorb soluble phosphate ions as insoluble calcium phosphates. They further concluded that generalizations on the behavior of added phosphorus cannot be based on pH values alone, but rather on the cation exchange capacity and the type of profile.

Scarseth and Tidmore (59) found that calcium carbonate decreased the availability of various phosphates. This effect decreased as the length of time the calcium carbonate had been in the soil increased from 0 to 365 days. When free calcium carbonate was no longer present in the soil the availability of the phosphates increased. It was thought that hydrolysis of calcium carbonate and calcium bicarbonate in the soil solution allowed the calcium to unite with the soluble phosphorus to form relatively insoluble tricalcium phosphate. When equilibrium was finally established between the calcium carbonate and the soil acids, that is, when all the available free calcium carbonate had been used up, more phosphorus was available and increased yields were obtained.

Pierre and Browning (55) suggested that the depression of phosphorus availability on several Iowa soils by an increase in lime was

not contradictory to previously established evidence. Plants grown on soils to which large amounts of lime had recently been added sometimes showed symptoms of phosphate starvation and responded markedly to high phosphate fertilization, but this temporary condition was gradually overcome and the lime slowly increased the availability of phosphorus. Working with several Michigan soils, Cook (17) was able to show that increasing the degree of base saturation resulted in significant increases in the amount of readily available phosphorus in seven soils and slight increases in two others. Lime also helped to preserve the availability of added soluble phosphates.

Although the effect of lime on the availability of potassium has been the subject of a number of studies, considerable variation in the results have been obtained. MacIntire and his associates (36) found that different liming materials reduced the loss of replaceable potassium in rainwater leachings from lysimeters over a fifteen-year period. They concluded that lime additions increase the proportion of solid-phase potash to soluble potash. Jenny and Shade (29) suggested that calcium carbonate may liberate adsorbed potassium, which in turn may be reabsorbed by microorganisms, the activity of the organisms having been favored by the lime treatment. This may account for the often noticed abnormalities in the release of potassium by lime.

Allaway and Pierre (3) found that as the content of free calcium carbonate in the surface layer of several unproductive Iowa soils increased, the content of exchangeable potassium decreased and fixation as nonexchangeable potassium increased. Other Iowa workers (54) felt that at least a part of the contradictory results of the effect of lime on potassium absorption obtained by various investigators could be explained on the basis of the species of plants used in the studies. Different plants are apparently affected in varying ways by different calcium and potassium levels and ratios.

Peech and Bradfield (51) have questioned whether moderate applications of lime under practical field conditions promote a significant conversion of native or added potassium into nonexchangeable forms. They found that on acid soils lime decreased the potassium in the soil solution due to the increase in the amount of adsorbed calcium. When applied to soils already well saturated with calcium, lime liberated the adsorbed potassium and increased its concentration in the soil solution. On slightly acid soils, where the influence of the small increase in the calcium saturation just offset the liberative effect of the calcium ions brought into solution, lime had no effect on the potassium concentration in the soil solution. The presence or absence of neutral salts of strong acids was also found to be a factor in determining the fixation or liberation of potassium by lime. The

authors concluded by stating that "when the experimental conditions are properly evaluated, the apparently conflicting results reported concerning the Ca:K relationships in the soil and in plants are indeed in fairly good agreement."

EXPERIMENTAL PROCEDURE

Field Studies

Three soils, Warsaw loam, Hillsdale sandy loam, and Kalkaska sand, were used in the present study. A general description of these soils has been given by Veatch (67).

With the exception of the Kalkaska location, the experimental areas were divided into six blocks separated by 15-foot alleys, each of which contained eight plots. At the Kalkaska location the area was divided into four blocks separated by 25-foot alleys, each block containing twelve plots. All plots were 50 feet long and 24 feet wide.

Lime was applied to the Cass County plots in October, 1953, and to the Hillsdale and Kalkaska plots in April and May of 1954, respectively. The lime requirement of these latter two groups of plots was determined by the method of Bradfield and Allison (12). From these values the amounts of lime necessary to apply in order to bring the pH levels to 6.0, 6.5, 7.0, and 7.5 were calculated. One-half of the lime was applied previous to plowing and one-half after plowing, using an 8-foot lime distributor calibrated to spread the required amount.

The type of lime used varied with the location depending upon the sources most widely used in the region. At the Hillsdale and Kalkaska locations calcitic and dolomitic limestones were compared. In addition, a pulverized dolomitic stone was used as a standard or reference material at both locations. A water-quenched calcium silicate slag was also included in the Kalkaska plots. In Cass County two dolomitic limestones differing only in degree of fineness were used at varying rates of application. Some of the characteristics of the various liming materials are given in Table I.

Soil samples were taken from all plots prior to treatment. Five samplings were obtained from the Cass County plots over a one-year period from October, 1953, to October, 1954. Similarly, four samplings were taken from the Hillsdale plots during the period from April, 1954, to April, 1955, while three samplings were obtained from the Kalkaska plots during the eleven-month period from May, 1954, to April, 1955. Each plot sample consisted of fifteen to twenty soil cores to a depth of 5 or 6 inches.

Greenhouse Studies

A greenhouse experiment was begun in September of 1954 using five soils, Warsaw loam, Hillsdale sandy loam, Kalkaska sand, Fox sandy loam, and Brookston clay loam. The Warsaw, Hillsdale,

TABLE I
SOME CHARACTERISTICS OF THE LIMING MATERIALS
USED IN THE EXPERIMENTS

Location of Experiment	Type	Grade
Cass County	Dolomitic	Pulverized
	Dolomitic	Meal
Hillsdale County	Calcitic	Meal
	Dolomitic	Pulverized
	Dolomitic ¹	Pulverized
Kalkaska County	Calcitic	Meal
	Dolomitic	Meal
	Dolomitic ¹	Pulverized
	Calcium Silicate	Slag
Greenhouse	Calcium Carbonate	
	Dolomitic ¹	Pulverized
	Calcium Silicate	Slag

¹ Pulverized dolomitic limestone used as a reference lime at all locations except Cass County.

TABLE I (Continued)

Source	Neutral- izing Value	Screen Analysis		
		Pct. Through 8 Mesh	Pct. Through 40 Mesh	Pct. Through 100 Mesh
Joliet, Ill.	108.6	98	90	71
Joliet, Ill.	108.6	63	14	6
Bellevue, Mich.	85.8	89	27	10
Woodville, Ohio	105.9	100	100	91
Woodville, Ohio	106.4	100	100	91
Charlevoix, Mich.	97.8	98	55	28
Drummond Island, Mich.	104.7	99	46	23
Woodville, Ohio	106.4	100	100	91
East Chicago, Ill.	87.4	95	46	22
	100.0	100	100	100
Woodville, Ohio	106.4	100	100	91
East Chicago, Ill.	87.4	95	46	22

and Kalkaska soils were obtained from the same areas in which field studies were being conducted. Some of the physical and chemical characteristics of these five soils are given in Table II.

Eight thousand grams of air-dried soil, which had previously been screened through a one-quarter inch screen, was placed in two-gallon glazed clay pots. Prior to potting, the soil was mixed with 5-20-20 fertilizer at the rate of 1,000 pounds per acre. Also, equivalent amounts of three liming materials, sufficient to satisfy the lime requirement as determined by the Bradfield-Allison method, were thoroughly mixed with the soil in each series of pots. Each of the treatments, as listed below, was replicated three times.

1. Reprecipitated calcium carbonate, neutralizing value 100.
2. Pulverized dolomitic limestone, neutralizing value 106.
3. Water-quenched calcium silicate slag, neutralizing value 87.
4. No lime.

On September 10, Ranger alfalfa was planted and later thinned to twelve plants per pot. The soil was maintained at or near the moisture equivalent throughout the growth period by the frequent addition of distilled water. The pots were arranged in a random manner on three large tables which could be rotated at regular intervals to lessen any bias due to a more favored position on the table. Artificial lights were used to lengthen the light period to fifteen or

TABLE II
SOME PHYSICAL AND CHEMICAL CHARACTERISTICS OF
THE SOILS USED IN THESE STUDIES

Soil Type	Location	Mechanical Analysis			Pct. Organic Matter	Cation Exchange Capacity
		Pct. Sand	Pct. Silt	Pct. Clay ¹		
Brook- ston clay loam	Sec 21, T6N, R2W, Cook Farm, Clinton County	40	31	29	3.69	16.49
Warsaw loam ²	Sec 20, T6S, R14W, Spencer Farm, Cass County	44	43	13	5.27	15.26
Hillsdale sandy loam	Sec 16, T6S, R4W, Marshall Farm, Hills- dale County	72	19	9	2.73	4.81
Fox sandy loam ³	Sec 31, T6N, R10E, Ferguson Farm, Lapeer County	74	19	7	1.58	4.67
Kalkaska sand	Sec 5, T20N, R6W, McCool Farm, Kalkaska County	90	7	3	1.02	3.17

¹ Less than 2 microns.

² This soil is now classified as Wea loam.

³ This soil is now classified as Metea sandy loam.

sixteen hours per day. Three cuttings of alfalfa were obtained from each culture over a six-month period ending March 10, 1955. The alfalfa growing in each pot was harvested when it reached a certain stage of maturity; that is, when three or four blossoms appeared. The harvested material was oven-dried at 60°C., weighed, ground in a Wiley mill, and saved for subsequent analysis.

Soil samples were taken from each pot at two-month intervals, a total of three samplings. Each sample consisted of three cores the entire depth of the pot.

METHODS OF ANALYSIS

Soils

The soil from each field and greenhouse sampling was air-dried and screened through a 2-millimeter sieve prior to analysis.

All pH measurements were made on 1:1 soil-water suspensions, using a Beckman Model H-2 glass electrode pH meter. The suspensions were stirred intermittently during a fifteen-minute period, after which the determinations were made. The method of Bradfield and Allison (12) was employed to determine the lime requirement of the original samples. The method used in determining exchange capacity and total exchangeable bases was similar to that outlined by Peech (50), except that the ammonia was determined by Kjeldahl distillation and subsequent titration rather than by nesslerization. Total exchangeable bases were determined directly by back titration of the acidified ammonium acetate residue, which had previously been ashed in a muffle furnace at 390°C. for thirty minutes.

Available phosphorus was measured by two methods, that of Spurway (63), using 0.13 N HCl as the extracting solution, and that of Bray (14), using a mixture of 0.025 N HCl and 0.03 N ammonium fluoride as the extracting solution. The Spurway method was also

employed for the determination of available potassium. Colorimetric determinations of phosphorus and potassium by the Spurway method were made with a Cenco-Sheard-Sanford Photoelometer, while a Lumetron Model 400-A Colorimeter was employed for determining phosphorus by the Bray method.

Mechanical analysis of the five soils studied was determined by the hydrometer method (11). The combustion train method of Hopper (27) was used to estimate the organic matter content.

Plants

The total phosphorus content of the alfalfa grown in the greenhouse was determined by the molybdivanadophosphoric acid method as outlined by Kitson and Mellon (33). A Coleman Model 14 Universal Spectrophotometer, equipped with a 4600 Angstrom filter, was used to measure light transmission.

Lime

The neutralizing values and screen analyses for the various liming materials were determined by the standard A.O.A.C. methods (6).

RESULTS AND DISCUSSION

Field Studies

Soil reaction. The effect of varying rates and fineness of dolomitic limestone on the rate of change of soil reaction in a Warsaw loam soil is given in Table III. Five months after lime application, the lower rate of application of pulverized dolomitic limestone had increased the soil pH slightly more than four-tenths of a unit, while the 10-ton application had raised it a full unit. The differences between the 6-, 8-, and 10-ton applications were very small. The dolomitic meal showed increases in pH ranging from about three-tenths of a unit with the 2-ton-per-acre application to a maximum of six- to seven-tenths of a unit with the 6-, 8-, and 10-ton rates. The more rapid rise in pH on those plots receiving the fine lime was due to the larger content of material which passed through a 100-mesh screen.

Two months later the majority of the plots showed a slight decrease in pH, this reduction being greatest on those plots which received the higher rates of application, especially where the fine lime was used. It is possible that part of this decrease may have been seasonal, due to the increased utilization of calcium by the

TABLE III

THE EFFECT OF RATE OF APPLICATION AND FINENESS OF
DOLOMITIC LIMESTONE ON THE RATE OF CHANGE OF
SOIL REACTION IN A WARSAW LOAM SOIL

Rate (tons per acre)	Fineness	Months After Lime Application				
		0 ^a (pH)	5 (pH)	7 (pH)	9 (pH)	12 (pH)
2	Fine	5.85 ^b	6.29	6.11	6.12	6.06
	Coarse	5.66	5.97	5.97	5.85	5.93
4	Fine	5.84	6.43	6.35	6.37	6.08
	Coarse	5.76	6.17	6.13	6.11	6.10
6	Fine	5.74	6.82	6.30	6.56	6.37
	Coarse	5.66	6.34	6.15	6.31	6.16
8	Fine	5.78	6.71	6.35	6.82	6.50
	Coarse	5.75	6.41	6.29	6.39	6.24
10	Fine	5.74	6.68	6.50	6.55	6.48
	Coarse	5.82	6.43	6.35	6.31	6.25
None		5.76	5.74	5.76	5.75	5.89

^a pH prior to lime application.

^b All pH values based on the average hydrogen-ion concentration of ~~three~~^{four} replications.

developing wheat plants, as well as to increased leaching of calcium and soluble salts caused by heavy spring rains.

Samples taken nine months after lime application, in July of 1954, indicated that only moderate changes in pH had taken place since the previous sampling. With the higher rates of application, gains in pH were almost sufficient to offset the decreases which occurred between the fifth- and seventh-month samplings. Hester and Shelton (25) attributed increasing soil acidity during the summer months to lighter rainfall and heavier evaporation from the soil and plants, thus decreasing the leaching of soluble salts. Bayer (7) suggested that an increase in soil acidity during the summer months was due to a dehydration of the soil colloids as well as an accumulation of soluble salts. It is possible that these factors may have restricted increases in pH throughout the summer season on the Cass County plots.

Twelve months after lime application, the differences in pH between areas treated with the pulverized and meal limes ranged from a low of about one-tenth of a unit to a high of three-tenths of a unit. These slight differences are no doubt indicative of the fact that a considerable portion of the fine lime had already reacted with the soil. The changes in soil reaction which took place during the twelve-month

interval as a result of applying six tons per acre of the two liming materials is further illustrated in Figure 1.

It is noteworthy that at no time during the course of the experiment did any of the plots reach neutrality, even with the 10-ton rates of application. This indicates a very high buffer capacity for the Warsaw loam, a prairie soil which is relatively high in organic matter.

On the Hillsdale sandy loam soil, calcium limestone meal at four levels of application was compared with two pulverized dolomitic limestones, one applied at the same relative rates, the other at only two rates. These two dolomitic stones were obtained from the same source, the one being a bulk lime, the other a bagged material which was used as a standard or reference lime in several experiments. The rate of application was determined from the lime requirement by calculating the amount of lime necessary to give a desired pH level. These pH levels were 6.0, 6.5, 7.0, and 7.5.

As indicated in Table IV, there was a moderate degree of correlation between the initial pH values and the lime requirement. The lime requirement varied considerably between plots, even prior to any treatment. The pH changes for all treatments were very slight during the one-year interval following incorporation of the lime into the soil. The data in Figure 2 illustrate the changes in

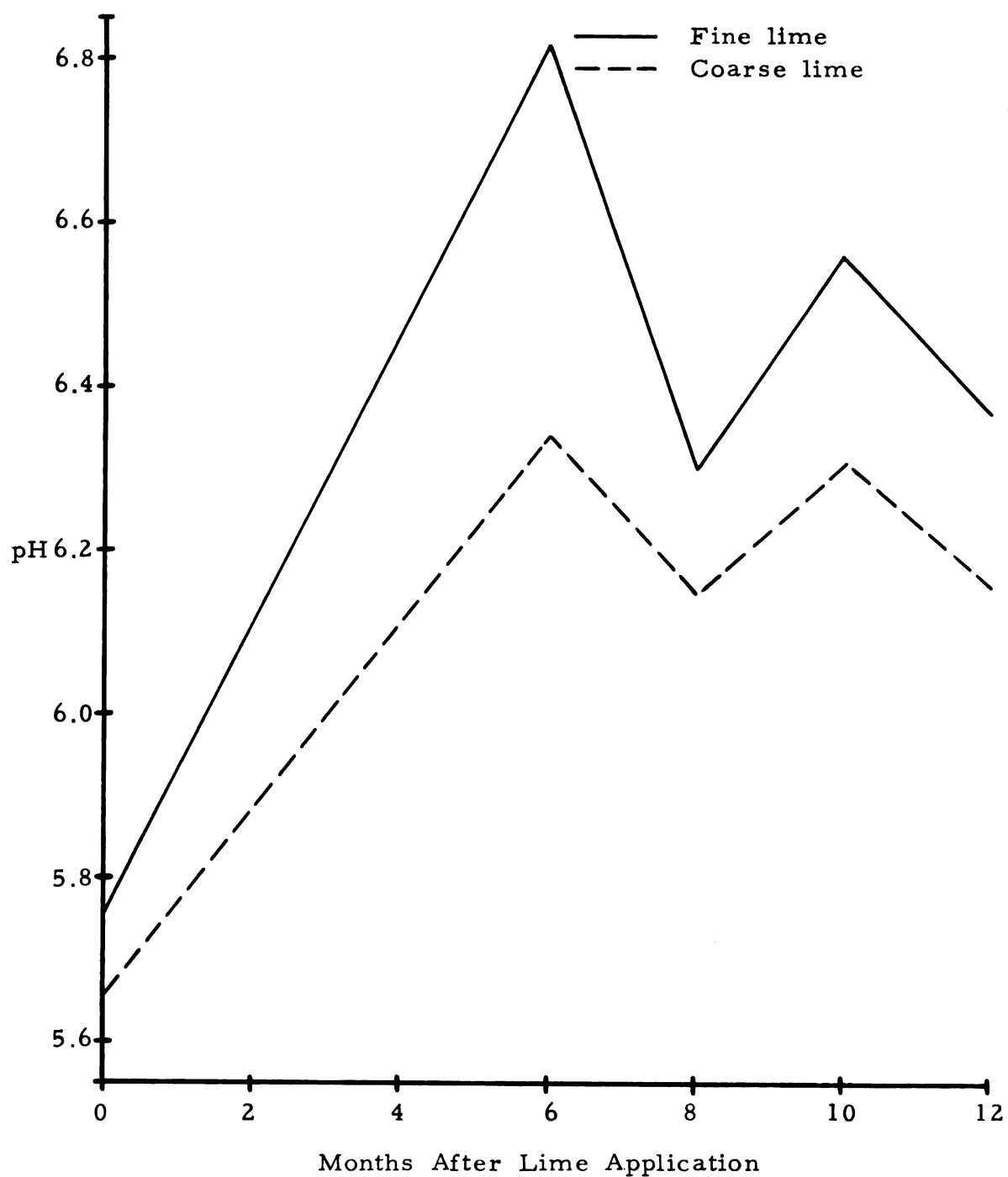


Figure 1. The effect of applying six tons per acre of fine and coarse dolomitic limestone on the rate of change of soil reaction in a Warsaw loam soil.

TABLE IV

THE EFFECT OF RATE OF APPLICATION AND TYPE OF LIME
ON THE RATE OF CHANGE OF SOIL REACTION IN A
HILLSDALE SANDY LOAM SOIL

Type of Lime	pH to be At- tained	Lime Re- quire- ment (lbs./ acre)	Rate of Appli- cation (lbs./ acre)	Months After Lime Application			
				0 ^a (pH)	3 (pH)	4 (pH)	12 (pH)
Calcitic lime- stone meal	6.0	10,000	3,300	5.54 ^b	5.64	5.85	6.06
	6.5	9,300	6,200	5.50	5.99	5.93	6.00
	7.0	7,800	8,000	5.59	5.94	6.05	6.14
	7.5	7,500	9,300	5.54	5.69	5.94	6.00
Pulverized dolomitic lime- stone	6.0	10,200	3,700	5.41	5.98	5.96	6.14
	6.5	9,100	6,200	5.48	5.77	6.08	6.00
	7.0	8,200	8,500	5.57	6.10	6.23	6.21
	7.5	6,600	8,700	5.62	6.34	6.18	6.41
Reference lime ^c	6.5	8,600	5,700	5.45	5.95	6.05	6.02
	7.0	8,200	8,500	5.50	6.06	6.20	6.25
No lime		8,700		5.52	5.40	5.39	5.61

Correlation coefficient between lime requirement and hydrogen-ion concentration before liming equals +0.450.**

^a pH prior to lime application.

^b All pH values based on the average hydrogen-ion concentration of four replications.

^c Pulverized dolomitic limestone.

** Significant at the 1 percent level.

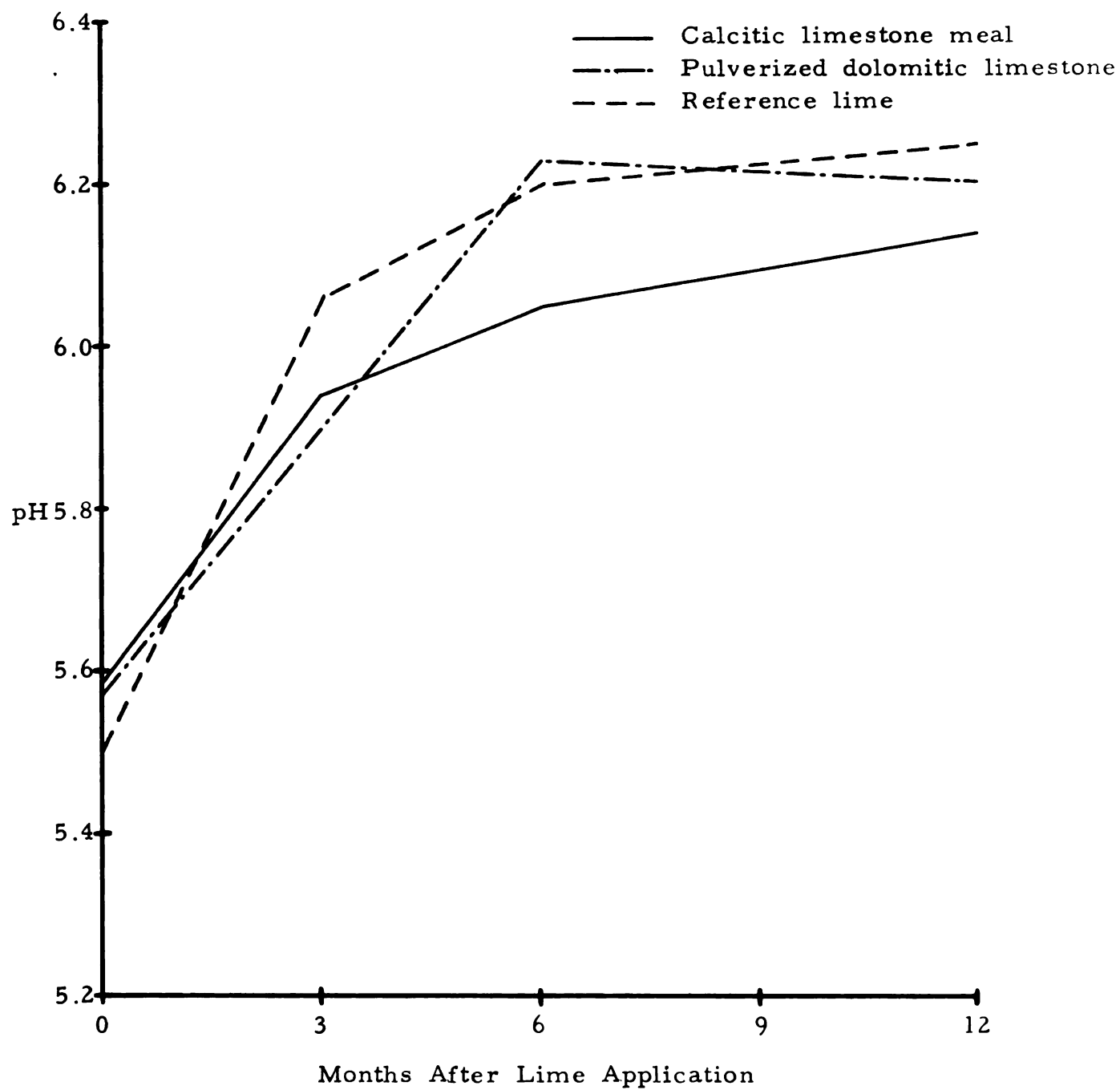


Figure 2. The effect of three liming materials, applied in amounts equal to the lime requirement, on the rate of change of soil reaction in a Hillsdale sandy loam soil.

pH which occurred during this time as a result of applying three liming materials in theoretically sufficient quantities to attain a pH of 7.0. Increases in pH were greatest with the high rates of application of pulverized dolomitic limestone. However, in spite of its greater degree of fineness and higher neutralizing value, these differences in pH were not appreciable. Similarly, within any group of treatments involving a particular type of lime, the pH differences were not related to the rates of application. Only at the lowest rate was the desired pH level attained. This would indicate that basing liming recommendations on the total lime requirement, or a fraction thereof, was not necessarily an accurate method. Dunn (22) has suggested the need to multiply the lime requirement by a "liming factor" in order to obtain the desired pH and degree of base saturation as a result of lime additions. This factor would vary depending on the climate, soil type, and kind of liming material.

At the Kalkaska location, dolomitic and calcitic limestone meals were applied at comparative rates of application, calculated to give the four pH levels indicated in Table V. In addition, a pulverized dolomitic limestone was applied at two levels and a water-quenched calcium silicate slag at one level.

The data in Table V show that the pH values attained at the end of one year after liming were much closer to the calculated

TABLE V

THE EFFECT OF RATE OF APPLICATION AND TYPE OF LIME
ON THE RATE OF CHANGE OF SOIL REACTION IN
A KALKASKA SAND SOIL

Type of Lime	pH to be At- tained	Lime Re- quire- ment (lbs./ acre)	Rate of Appli- cation (lbs./ acre)	Months After Lime Application		
				0 ^a (pH)	6 (pH)	12 (pH)
Calcitic limestone meal	6.0	6,500	2,200	5.08 ^b	6.00	6.06
	6.5	5,800	3,900	5.33	6.43	6.50
	7.0	5,800	5,800	5.54	6.79	6.88
	7.5	4,400	5,800	6.01	7.17	7.17
Dolomitic limestone meal	6.0	6,500	2,200	5.05	6.02	5.91
	6.5	5,800	3,900	5.47	6.41	6.44
	7.0	5,100	5,100	5.67	6.61	6.58
	7.5	4,400	5,800	5.94	6.77	6.86
Reference lime ^c	6.5	6,500	4,400	5.10	6.79	6.52
	7.0	4,400	4,400	6.07	7.20	7.21
Calcium silicate slag	7.0	5,400	5,400	5.28	6.17	6.03
No lime		4,800		5.51	5.82	6.02

Correlation coefficient between lime requirement and hydrogen-ion concentration before liming equals +0.802.**

^a pH prior to lime application.

^b All pH values based on the average hydrogen-ion concentration of four replications.

^c Pulverized dolomitic limestone.

** Significant at the 1 percent level.

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levels than was the case with the Hillsdale soil. This may be due to the very low organic matter and clay content of this soil, resulting in a low exchange capacity and low buffer capacity. Similarly there was a much higher degree of correlation between the initial pH values and the lime requirement with this soil than with the Hillsdale soil.

The calcitic limestone meal increased the pH only slightly more rapidly than the dolomitic limestone of similar fineness. Although the dolomitic stone was slightly coarser, it also was somewhat higher in neutralizing value. The pulverized dolomitic lime raised the pH more than either of the meals due to its greater proportion of fine material. The water-quenched calcium silicate slag increased the pH more slowly than did the same level of application of the other three limes. This can be attributed to the lower neutralizing value and solubility of this material.

A further illustration of the changes in pH which occurred as a result of applying the four liming materials in sufficient amounts to theoretically attain pH 7.0 is given in Figure 3.

Exchangeable bases and percent base saturation. The effect of lime on the content of exchangeable bases and the percent base saturation of the Warsaw loam soil is given in Table VI. It is evident from these data that the values for these two soil properties

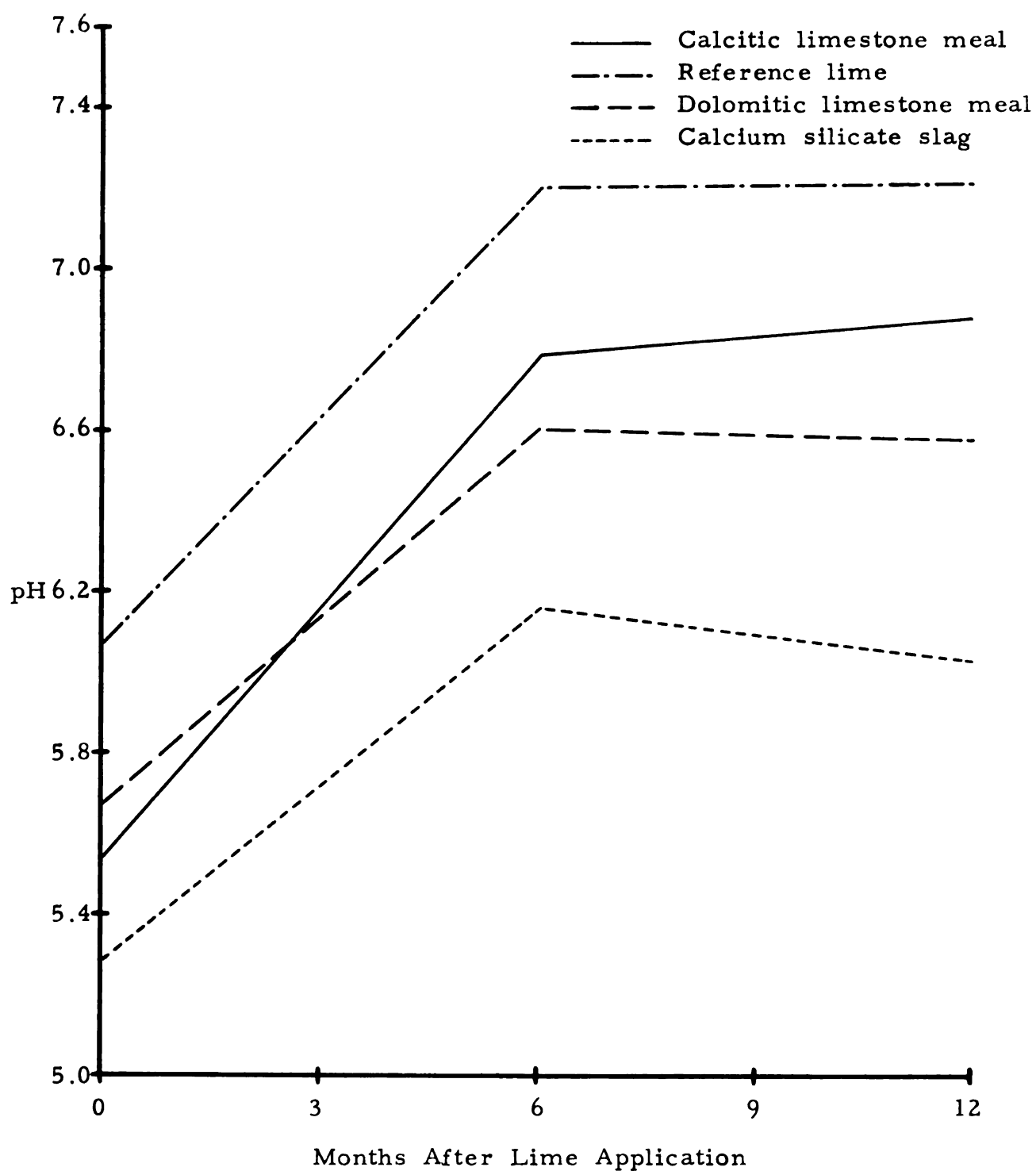


Figure 3. The effect of four liming materials, applied in amounts equal to the lime requirement, on the rate of change of soil reaction in a Kalkaska sand soil.

TABLE VI

THE EFFECT OF RATE OF APPLICATION AND FINENESS OF
DOLOMITIC LIMESTONE ON THE CONTENT OF EXCHANGE-
ABLE BASES AND THE PERCENT BASE SATURATION OF
A WARSAW LOAM SOIL

Rate (tons per acre)	Fine- ness	Cation Ex- change Ca- pacity ^a	Total Exchange- able Bases ^a		
			Months After Lime Application		
			0 ^b	5	7
2	Fine	15.21 ^c	10.31	12.75	10.76
	Coarse	14.50	9.02	10.60	10.17
4	Fine	14.67	9.76	11.97	11.11
	Coarse	16.73	10.25	12.15	10.36
6	Fine	15.21	9.62	13.87	10.77
	Coarse	15.59	9.98	12.25	10.53
8	Fine	14.87	9.06	13.46	10.23
	Coarse	15.68	10.30	12.63	11.10
10	Fine	14.54	9.33	13.32	11.27
	Coarse	15.37	9.82	12.82	10.37
None		15.53	9.61	10.86	10.13

Correlation coefficients for total changes^d in hydrogen-ion concentration vs. changes in the content of exchangeable bases and percent

^a Milliequivalents per 100 grams soil.

^b Prior to lime application.

^c All values represent the average of four replications.

TABLE VI (Continued)

Total Exchange- able Bases ^a		Percent Base Saturation				
Months After Lime Application		Months After Lime Application				
9	12	0 ^b	5	7	9	12
12.41	11.57	67.7	83.8	70.7	81.6	76.1
11.10	11.12	62.2	73.1	70.1	76.6	76.7
12.30	11.98	66.5	81.6	76.7	83.8	81.7
13.07	12.25	61.3	72.6	61.9	78.1	77.2
13.73	12.61	63.2	91.2	70.8	90.3	82.9
12.97	12.12	64.0	78.6	67.5	83.2	77.7
13.45	12.87	60.9	90.5	68.8	90.5	86.6
13.39	12.22	66.3	80.5	70.8	85.4	77.9
12.97	13.58	64.2	91.6	77.5	89.2	93.4
11.91	12.73	63.9	83.4	67.5	77.5	82.8
11.22	11.35	61.9	70.0	65.2	72.3	73.1

base saturation equal +0.325* and +0.329,* respectively.

^d Based on the difference between initial and final samplings.

* Significant at the 5 percent level.

approximate that of the change in pH, reaching a high in the fifth month and then declining slightly, or remaining about the same, until the October, 1954, sampling, twelve months after lime application. Here, too, it can be seen that the finer material exerted its maximum influence sooner than did the coarse lime, and at the end of one year this difference was relatively small. When the total decrease in hydrogen-ion concentration from the initial to the final samplings was correlated with changes in the content of exchangeable bases and the percent base saturation over the same period of time, values of 0.325 and +0.329, respectively, were obtained. These values were significant at the 5 percent level, indicating a general but imperfect relationship between these properties. Shimp (62), in his studies on a number of Michigan soils, found similar results.

Table VII contains similar data for experiments conducted on the Hillsdale sandy loam soil. However, in this instance, the correlation between changes in the hydrogen-ion concentration and changes in the content of exchangeable bases and the percent base saturation was more perfect, in that the correlation coefficients were significant at the 1 percent level. Also, a moderate degree of correlation existed between the initial percent base saturation and the lime requirement.

These data, like those for pH, show the lack of appreciable differences between any of the materials used or rates of application.

TABLE VII

THE EFFECT OF RATE OF APPLICATION AND TYPE OF LIME
ON THE CONTENT OF EXCHANGEABLE BASES AND THE
PERCENT BASE SATURATION OF A HILLSDALE
SANDY LOAM SOIL

Type of Lime	Rate (lbs. per acre)	pH to be At- tained	Cation Ex- change Ca- pacity ^a
Calcitic limestone meal	3,300	6.0	4.90 ^c
	6,200	6.5	4.75
	8,000	7.0	4.32
	9,300	7.5	4.87
Pulverized dolomitic limestone	3,700	6.0	4.89
	6,200	6.5	5.11
	8,500	7.0	5.05
	8,700	7.5	4.76
Reference lime ^d	5,700	6.5	4.85
	8,500	7.0	4.69
No lime			4.76
Correlation coefficients for total changes ^e in hydrogen-ion concentration vs. changes in the content of total exchangeable bases and the percent base saturation equal +0.648** and +0.669,** respectively.			

^a Milliequivalents per 100 grams soil.

^b Prior to liming.

^c All values represent the average of four replications.

TABLE VII (Continued)

Total Exchange- able Bases ^a				Percent Base Saturation			
0 ^b	Months After Lime Application			0 ^b	Months After Lime Application		
	3	6	12		3	6	12
2.35	3.05	3.15	3.55	48.2	62.7	64.0	72.6
2.17	3.34	3.60	3.13	45.9	71.5	75.8	65.4
2.42	3.34	3.32	3.34	56.1	78.0	77.8	78.3
2.31	3.11	3.44	3.42	47.8	64.7	68.9	70.7
2.30	3.38	3.44	3.14	47.1	64.5	70.4	69.8
2.16	3.14	3.51	3.42	42.8	62.7	69.2	68.0
2.45	3.83	4.07	3.48	48.4	75.6	80.5	76.4
2.65	3.78	4.24	3.87	55.8	78.6	88.9	80.3
2.26	3.19	3.25	3.24	46.7	65.9	67.1	66.5
2.15	3.27	3.76	3.62	46.1	70.0	79.9	77.3
2.24	2.35	2.41	2.44	47.2	49.5	50.8	51.7

Correlation coefficient between lime requirement and percent base saturation prior to liming equals -0.455.**

^d Pulverized dolomitic limestone.

^e Based on the difference between initial and final samplings.

** Significant at the 1 percent level.

The differences at the end of one year were not as large as anticipated in view of the fact that the calcitic meal was not only lower in neutralizing value than the pulverized dolomitic limestone, but also contained only 10 percent of material which passed a 100-mesh screen compared to 91 percent for the latter material.

The content of exchangeable bases and the percent base saturation of the Kalkaska sand soil at two intervals after liming are given in Table VIII. It will be noted that the data for this soil are considerably more variable, even prior to lime applications. However, there was a high negative correlation between the initial percent base saturation and the lime requirement.

With the two highest rates of application of calcium lime and the highest rate of the pulverized dolomitic limestone, the percent base saturation has exceeded 100 percent, indicating the presence of free carbonates. These saturations correspond to pH values close to, or slightly over, 7.0.

Even with relatively small applications of lime to the Kalkaska sand soil, the increases in the content of exchangeable bases and the percent base saturation were much larger than those obtained by the highest amounts of lime applied to the two previously described soils. This is not surprising in view of the low exchange capacity and buffer capacity of this soil.

TABLE VIII

THE EFFECT OF RATE OF APPLICATION AND TYPE OF LIME
ON THE CONTENT OF EXCHANGEABLE BASES AND THE
PERCENT BASE SATURATION OF A
KALKASKA SAND SOIL

Type of Lime	Rate (lbs. per acre)	pH to be At- tained	Cation Ex- change Ca- pacity ^a
Calcitic limestone meal	2,200	6.0	3.35 ^c
	3,900	6.5	3.15
	5,800	7.0	3.11
	5,800	7.5	3.40
Dolomitic limestone meal	2,200	6.0	2.84
	3,900	6.5	3.16
	5,100	7.0	3.39
	5,800	7.5	3.00
Reference lime ^d	4,400	6.5	2.93
	4,400	7.0	3.30
Calcium silicate slag	5,400	7.0	3.07
No lime			3.33

Correlation coefficients for total changes^e in hydrogen-ion concentration vs. changes in the content of total exchangeable bases and the percent base saturation equal +0.354* and +0.267, respectively.

^a Milliequivalents per 100 grams soil.

^b Prior to lime application.

^c All values represent the average of four replications.

TABLE VIII (Continued)

Total Exchange- able Bases ^a			Percent Base Saturation		
0 ^b	Months After Lime Application		0 ^b	Months After Lime Application	
	6	12		6	12
0.75	1.95	1.77	22.4	58.2	52.8
1.15	2.66	2.63	37.0	85.5	83.5
1.45	3.26	3.16	46.6	104.8	101.6
2.42	4.03	4.00	71.2	118.5	117.6
0.46	1.74	1.45	16.2	61.3	51.1
1.41	2.36	2.53	44.6	74.7	80.1
2.00	2.82	2.89	59.3	83.7	85.3
2.05	2.91	2.94	68.3	97.0	98.0
0.66	2.58	2.37	22.5	88.1	80.9
2.45	3.46	3.43	74.2	104.8	103.9
1.26	2.31	2.14	71.0	75.2	69.7
1.79	2.40	2.28	53.8	72.1	68.5

Correlation coefficient between lime requirement and percent base saturation prior to liming equals -0.931.**

^d Pulverized dolomitic limestone.

^e Based on the difference between initial and final samplings.

* Significant at the 5 percent level; ** significant at the 1 Percent level.

A comparison between the pH values resulting from the various treatments and the content of exchangeable bases and the percent base saturation would indicate a close relationship between these properties. However, due to the wide variations between replicates, the correlation between changes in the hydrogen-ion concentration and changes in the above two properties one year after liming was less perfect than for the Warsaw and Hillsdale soils. Bray and DeTurk (13) found poor correlation between pH values and degree of base saturation in soils less than 60 percent saturated.

Bear and Toth (9), as well as the above investigators, have suggested that 80 percent base saturation is ideal for most soils. It is impractical, because of losses by leaching, to maintain higher pH levels. In the Warsaw and Hillsdale soils this would mean a pH of approximately 6.0 to 6.3, while with the Kalkaska soil the pH should be about 6.3 to 6.5 to give this degree of saturation. The rate of application of lime to attain this level would depend on the type and fineness of the lime and the base saturation prior to the addition of lime.

Availability of phosphorus and potassium. The effect of lime on the availability of phosphorus and potassium in the Warsaw, Hillsdale, and Kalkaska soils is given in Tables IX, X, and XI, respectively.

TABLE IX

THE EFFECT OF RATE OF APPLICATION AND FINENESS OF
DOLOMITIC LIMESTONE ON THE AVAILABILITY OF
PHOSPHORUS AND POTASSIUM IN A
WARSAW LOAM SOIL

Rate (tons per acre)	Fineness	Bray's Adsorbed Phosphorus ^a				
		Months 0 ^b	After 5	Lime 7	Application 9	
					12	
2	Fine	15.8 ^c	22.5	19.3	27.1	26.4
	Coarse	18.9	25.5	24.7	28.8	27.7
4	Fine	15.0	27.7	19.8	21.9	27.9
	Coarse	15.5	29.3	23.8	28.6	24.9
6	Fine	17.9	23.3	23.2	28.1	25.7
	Coarse	15.1	25.1	30.7	31.2	27.8
8	Fine	16.2	25.1	21.4	27.5	20.3
	Coarse	29.7	32.9	25.1	21.4	23.2
10	Fine	18.7	24.0	24.9	26.3	25.9
	Coarse	17.2	26.1	27.9	22.2	22.2
None		17.1	30.1	32.1	34.0	27.4

Correlation coefficients for total^g changes in hydrogen-ion concentration vs. changes in the availability of phosphorus (as measured

^a Phosphorus extracted by 0.025 N HCl and 0.03 N NH₄F.

^b Prior to lime application.

^c All values represent the average of four replications, expressed in pounds per acre.

^d Phosphorus and potassium extracted by 0.13 N HCl.

TABLE IX (Continued)

Spurway's Reserve Phosphorus ^d					Spurway's Reserve Potassium ^d				
Months After Lime Application 0 ^e	5	7	9	12	Months After Lime Application 0 ^e	5	7	9	12
4.3 ^f	6.9	7.8	15.1	16.5	62	115	90	100	118
3.8	8.0	9.4	14.4	14.8	74	131	90	124	113
3.5	10.1	9.3	13.4	18.9	37	121	89	88	108
3.5	7.9	11.0	14.9	13.6	80	120	80	125	133
3.8	7.9	8.4	14.9	17.9	70	151	103	139	129
4.5	8.5	17.5	14.9	17.1	83	144	95	115	145
3.5	10.3	9.5	12.8	13.0	56	146	93	124	115
7.0	9.3	8.5	11.4	13.5	50	135	118	135	119
4.5	9.4	13.0	16.0	19.0	62	131	89	92	120
5.0	10.3	12.5	11.0	13.3	66	137	80	105	119
4.3	8.3	9.4	13.9	14.4	57	136	90	117	131

by the Bray Adsorbed and Spurway Reserve methods) and potassium equal -0.060, -0.044, and -0.085, respectively.^h

^e Prior to lime application.

^f All values represent the average of four replications, expressed in pounds per acre.

^g Based on the difference between initial and final samplings.

^h Not significant at the 5 percent level.

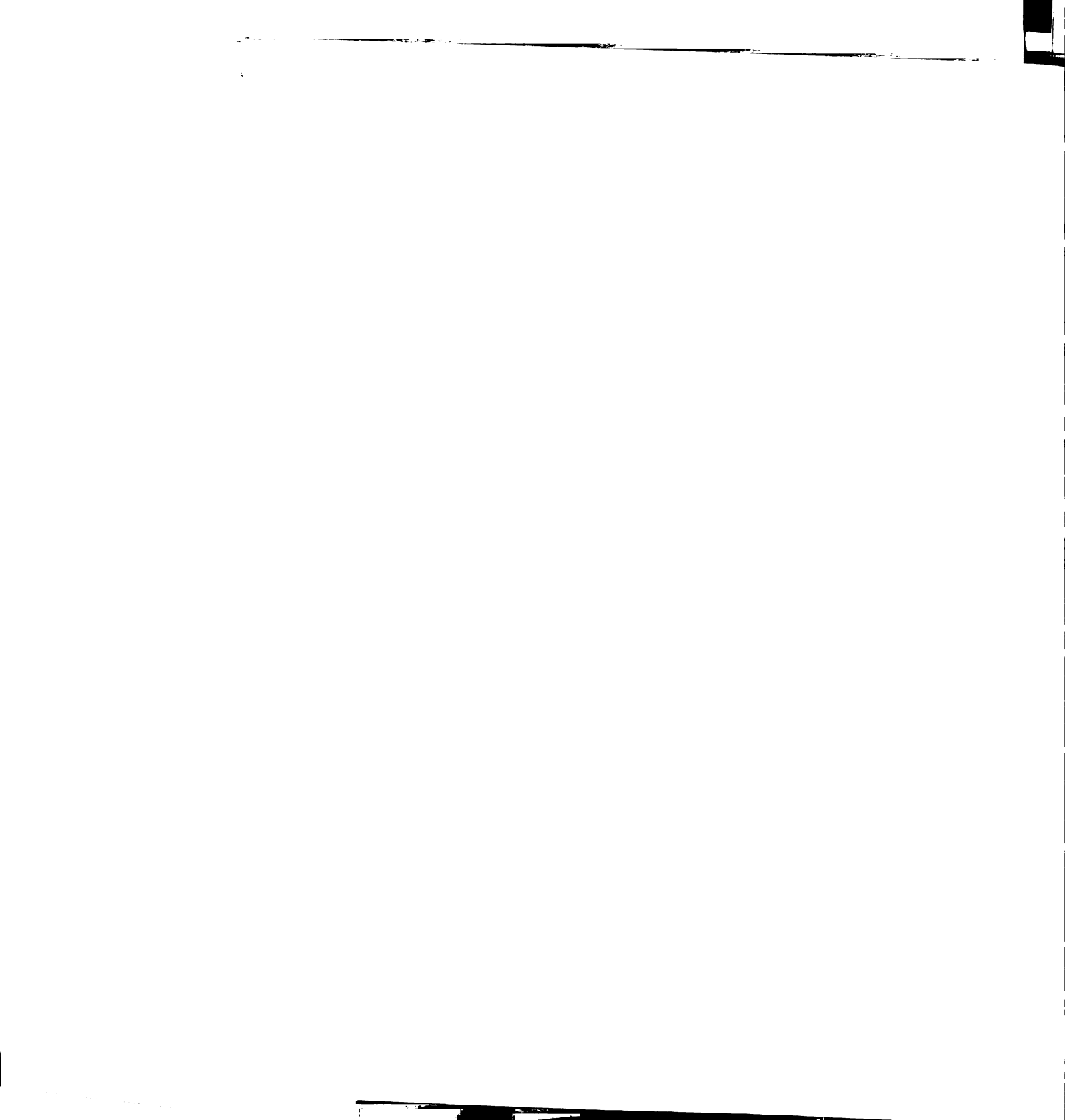


TABLE X

THE EFFECT OF TYPE AND RATE OF APPLICATION OF LIME
ON THE AVAILABILITY OF PHOSPHORUS AND POTASSIUM
IN A HILLSDALE SANDY LOAM SOIL

Type of Lime	Rate (lbs. per acre)	pH to be At- tained	Bray's Adsorbed Phosphorus ^a			
			Months After 0 ^b	3	7	12
Calcitic lime- stone meal	3,300	6.0	71.8 ^c	44.0	42.2	43.9
	6,200	6.5	84.9	60.7	56.0	57.2
	8,000	7.0	51.5	44.9	42.5	47.8
	9,300	7.5	56.9	41.7	40.3	46.7
Pulverized dolomitic limestone	3,700	6.0	66.6	49.1	41.1	51.4
	6,200	6.5	76.5	51.9	51.4	51.5
	8,500	7.0	64.5	44.9	42.5	52.0
	8,700	7.5	57.8	43.1	40.1	42.0
Reference lime ^d	5,700	6.5	94.2	76.1	57.2	68.3
	8,500	7.0	90.3	58.3	52.7	56.2
No lime			78.5	55.4	55.4	58.2

Correlation coefficients for total changes^f in hydrogen-ion concentration and changes in the availability of phosphorus (as measured

^a Phosphorus extracted by 0.025 N HCl and 0.03 N NH_4F .

^b Prior to lime application.

^c All values represent the average of four replications, expressed in pounds per acre.

^d Pulverized dolomitic limestone.

TABLE X (Continued)

Spurway's Reserve Phosphorus ^e				Spurway's Reserve Potassium ^e			
Months After Lime Application				Months After Lime Application			
0 ^b	3	7	12	0 ^b	3	7	12
16.8 ^c	14.3	18.0	19.4	111	105	79	107
19.0	23.9	27.3	25.6	104	105	80	101
13.8	18.6	20.0	23.0	103	113	82	106
12.8	14.8	17.6	23.0	107	100	86	111
13.1	15.4	16.1	24.1	83	99	69	116
18.8	16.6	20.6	19.6	90	86	91	121
17.5	15.9	15.9	25.1	121	106	88	134
17.8	16.5	18.8	19.8	103	128	89	122
19.5	21.5	22.6	23.4	97	91	86	115
17.3	18.3	21.4	27.5	92	102	82	117
16.8	19.6	19.6	21.9	102	101	90	113

by the Bray Adsorbed and Spurway Reserve methods) and potassium equal +0.071, -0.080, and +0.245, respectively.^g

^e Phosphorus and potassium extracted by 0.13 N HCl.

^f Based on the difference between initial and final samplings.

^g Not significant at the 5 percent level.

TABLE XI

THE EFFECT OF RATE OF APPLICATION AND TYPE OF LIME
ON THE AVAILABILITY OF PHOSPHORUS AND
POTASSIUM IN A KALKASKA SAND SOIL

Type of Lime	Rate (lbs. per acre)	pH to be At- tained	Bray's Adsorbed Phosphorus ^a		
			Months After 0 ^b	6	12
Calcitic lime- stone meal	2,200	6.0	60.1 ^c	46.4	46.9
	3,900	6.5	49.1	46.3	43.2
	5,800	7.0	58.5	40.8	49.4
	5,800	7.5	42.7	48.6	41.1
Dolomitic limestone meal	2,200	6.0	44.2	53.6	49.9
	3,900	6.5	72.9	52.9	47.4
	5,100	7.0	54.3	51.5	42.4
	5,800	7.5	54.0	45.5	42.4
Reference lime ^d	4,400	6.5	67.9	51.1	50.9
	4,400	7.0	55.9	49.0	48.1
Calcium sili- cate slag	5,400	7.0	51.5	53.0	47.5
No lime			58.3	53.0	47.5
Correlation coefficients for total changes ^f in hydrogen-ion concen- tration vs. changes in the availability of phosphorus (as measured					

^a Phosphorus extracted by 0.025 N HCl and 0.03 N NH₄F.

^b Prior to lime application.

^c All values represent the average of four replications, ex-
pressed in pounds per acre.

^d Pulverized dolomitic limestone.

TABLE XI (Continued)

Spurway's Reserve Phosphorus ^e			Spurway's Reserve Potassium ^e		
Months After 0 ^b	Lime 6	Application 12	Months After 0 ^b	Lime 6	Application 12
26.3 ^c	25.5	31.8	115	114	102
27.8	35.5	28.4	117	130	107
25.4	36.4	34.0	134	134	115
33.0	44.0	40.4	141	131	121
15.1	28.6	29.6	120	116	101
27.8	30.9	30.6	133	127	125
34.3	38.3	35.0	152	133	107
28.6	34.1	39.0	123	132	128
25.0	37.3	33.0	95	119	109
31.5	44.3	43.5	119	147	124
38.5	43.0	27.8	119	143	122
38.3	33.8	34.6	128	105	119

by the Bray Adsorbed and the Spurway Reserve methods) and potassium equal +0.146, -0.128, and +0.113, respectively.^g

^e Phosphorus and potassium extracted by 0.13 N HCl.

^f Based on the difference between the initial and final samplings.

^g Not significant at the 5 percent level.

Phosphorus was measured by both the Bray Adsorbed (14) and the Spurway Reserve (63) methods. Potassium was determined by the Spurway Reserve method.

In the Warsaw loam soil, both the phosphorus content, as measured by the two methods, and the potassium content, increased throughout the year. However, the differences in values for "available" phosphorus and potassium between lime treatments varied widely from sampling to sampling. When changes in the hydrogen-ion concentration were correlated with changes in the availability of these two elements over the period of study, no appreciable degree of correlation was found.

The same variability with sampling period existed in the Hillsdale plots. The phosphorus content, as measured by the Bray method, decreased slightly during the one-year interval after liming, while the Spurway method showed a slight increase in the level of available phosphorus. However, changes in the availability of phosphorus gave negligible correlation with increasing pH as a result of lime applications. The potassium content increased somewhat during the period of study. Although there was a tendency for the level of available potassium to increase with decreasing hydrogen-ion concentration, the correlation coefficient for changes in these two properties from the initial to final samplings was not significant.

Similar results were obtained in the experiment with Kalkaska sand. Variations between samplings and the lack of any consistent trends between treatments in the same sampling masked the over-all effect of lime upon the availability of phosphorus and potassium. No significant correlation was found between changes in the level of these two elements one year after liming and changes in the hydrogen-ion concentration.

The lack of correlation between increasing pH and the availability of phosphorus in these three soils is contradictory to the findings of other investigators (17, 66), who found that liming moderately or strongly acid soils to a point where the pH was about 6.5 increased the availability of phosphorus. It is possible, however, that this is a temporary condition resulting from the recent addition of relatively large amounts of lime to these three soils. This condition may gradually be overcome and the lime will slowly increase the availability of phosphorus. Scarseth and Tidmore (59) found that when free calcium carbonate was no longer present in the soil, lime increased the availability of phosphorus. They thought that calcium ions resulting from hydrolysis of calcium carbonate and calcium bicarbonate in the soil solution combined with the soluble phosphorus to form relatively insoluble tricalcium phosphates. As previously suggested, the

variation in the data from sampling to sampling may have masked any real differences which were present.

Crop yields. Winter wheat was grown on the Warsaw loam soil in 1954 and 1955. No yields were obtained in 1954, the first crop season following liming. The 1955 yields, contained in Table XII, show no significant differences due to lime application.

Table XIII gives the 1954 yields of corn and the 1955 yields of oats grown on the Hillsdale sandy loam plots. No significant differences in yield occurred in either year, although there was a slight trend toward higher corn yields from the dolomitic limestone plots during the first year following lime application.

The effect of lime on the yield of sweet clover grown on the Kalkaska sand is given in Table XIV. Sweet clover was planted in early September of 1954, about ten weeks after the final application of lime. Hay yields were obtained in June of 1955.

Pulverized dolomitic limestone and calcium meal at the highest rates of application resulted in significantly higher yields of clover than did the two lowest rates of calcium meal and the lowest rate of dolomitic meal. The check plots and those treated with calcium and dolomitic meal applied at the pH 7.0 level, dolomitic meal at the pH 7.5 rate and the calcium silicate slag yielded more than

TABLE XII

THE EFFECT OF RATE OF APPLICATION AND FINENESS OF
DOLOMITIC LIMESTONE ON THE YIELD OF WINTER
WHEAT GROWN ON A WARSAW LOAM SOIL

Rate (tons/acre)	Fineness	Yield ^a (bu./acre)
2	Fine	23.3 ^b
	Coarse	22.2
4	Fine	23.8
	Coarse	24.1
6	Fine	24.9
	Coarse	26.2
8	Fine	21.8
	Coarse	24.1
10	Fine	22.3
	Coarse	22.8
None		21.2
L.S.D. (05)		N.S.

^a Second crop year after lime application.

^b All values represent the average of four replications.

TABLE XIII

THE EFFECT OF RATE OF APPLICATION AND TYPE OF LIME
ON THE YIELD OF CORN AND OATS GROWN ON A
HILLSDALE SANDY LOAM SOIL

Type of Lime	Rate (lbs. per acre)	pH to be At- tained	1954 Corn (bu./ acre)	1955 Oats (bu./ acre)
Calcitic limestone meal	3,300	6.0	85.0 ^a	44.7
	6,200	6.5	88.8	43.5
	8,000	7.0	88.5	34.3
	9,300	7.5	87.0	41.9
Pulverized dolomitic lime- stone	3,700	6.0	96.3	45.1
	6,200	6.5	94.8	43.3
	8,500	7.0	94.8	46.9
	8,700	7.5	94.8	38.4
Reference lime ^b	5,700	6.5	87.5	48.0
	8,700	7.0	95.8	39.0
No lime		5.6 ^c	86.0	37.8
L.S.D. (05)			N.S.	N.S.

^a All values represent the average of four replications.

^b Pulverized dolomitic limestone.

^c pH at the end of one year.

TABLE XIV

THE EFFECT OF RATE OF APPLICATION AND TYPE OF LIME
ON THE YIELD OF SWEET CLOVER GROWN ON
A KALKASKA SAND SOIL

Type of Lime	Rate (lbs. per acre)	pH to be At- tained	Yield ^a (tons per acre)
Calcitic limestone meal	2,200	6.0	0.56 ^b
	3,900	6.5	0.60
	5,800	7.0	0.91
	5,800	7.5	1.00
Dolomitic limestone meal	2,200	6.0	0.40
	3,900	6.5	0.74
	5,100	7.0	0.91
	5,800	7.5	0.82
Reference lime ^c	4,400	6.5	0.69
	4,400	7.0	1.05
Calcium silicate slag	5,400	7.0	0.88
No lime		6.0 ^d	0.82
L.S.D. (05)			0.37
(01)			0.49

^a Air-dry weight.

^b All values represent the average of four replications.

^c Pulverized dolomitic limestone.

^d pH at the end of one year.

did the plots which received the low rate of application of dolomitic meal. The relatively high yield of hay from the unlimed plots was probably due to a slightly better stand of sweet clover and to the higher degree of base saturation initially compared to those plots receiving the lower rates of application. The mean yield of the calcium meal plots was not significantly higher than the mean yield of the dolomitic meal plots. However, the mean yield caused by the two pulverized dolomitic limestone treatments was significantly higher than that obtained where the pH was brought to similar levels by calcium and dolomitic meals.

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Soil reaction. These data are presented in Table XV. Lime, sufficient to satisfy the lime requirement as determined by the Bradfield-Allison method (12), was mixed with the entire volume of soil just prior to planting alfalfa. Soil samples were obtained at two-, four-, and six-month intervals after liming.

With the exception of the Warsaw loam soil, calcium carbonate had increased the pH above 7.0 at the end of two months' time. The pulverized dolomitic limestone was somewhat slower in increasing the pH, probably due to lower solubility and a smaller percentage of fine material. The calcium silicate slag was the slowest of the

TABLE XV

THE EFFECT OF THREE LIMING MATERIALS ON THE RATE OF
CHANGE OF SOIL REACTION IN FIVE GREENHOUSE SOILS

Soil Type	Months After Lime Application	pH			
		No Lime	Calcium Carbonate	Pulverized Dolomite	Calcium Silicate Slag
Brookston	0 ^a	5.95 ^b	5.95	5.95	5.95
	2	5.95	7.46	6.82	6.56
	4	6.19	7.66	7.03	6.78
	6	6.10	7.55	7.06	6.70
Warsaw	0	5.45	5.45	5.45	5.45
	2	5.25	6.83	6.58	5.59
	4	5.63	7.07	7.06	6.09
	6	5.55	7.12	6.96	6.00
Hillsdale	0	5.20	5.20	5.20	5.20
	2	4.86	7.23	6.59	5.46
	4	5.05	7.14	6.81	5.70
	6	5.29	7.45	7.00	6.80
Fox	0	6.20	6.20	6.20	6.20
	2	5.89	7.43	6.79	6.10
	4	6.20	7.52	7.12	6.62
	6	6.12	7.48	7.10	6.50
Kalkaska	0	5.25	5.25	5.25	5.25
	2	5.23	7.69	6.96	5.66
	4	5.59	7.86	7.52	6.19
	6	5.42	7.69	7.18	6.01

^a Prior to lime application.

^b All values represent the average hydrogen-ion concentration of three replications.

materials used in raising soil reaction. With the exception of the soil to which the slag lime was added, pH 7.0 had been exceeded on all soils at the end of six months' time.

Table XVI contains the yield data for alfalfa grown on the five soils treated with three liming materials. No significant increases in yield were obtained for any of the lime applications to Brookston clay loam or Fox sandy loam. These two soils had an initial pH of six or above. Only on the Kalkaska soil did lime bring about a significant difference between yields for all three cuttings. In the first cutting the pulverized dolomitic lime and the calcium silicate slag produced significantly higher yields than did the check. This was also the case with the second cutting. The data of the third cutting show that all three liming materials increased the yield over that obtained without lime. However, the total yields show that only where the dolomitic and slag materials were used were the differences significant. The beneficial results obtained from the use of calcium silicate slag are interesting in view of the slow increase in pH which resulted from the use of this lime compared to the other two materials.

The only instance in which a significant increase in yield of alfalfa was obtained as a result of lime additions to the Warsaw loam soil was at the second cutting. Here the calcium carbonate produced

TABLE XVI

THE EFFECT OF THREE LIMING MATERIALS ON THE YIELD
OF ALFALFA GROWN ON FIVE SOILS IN THE GREENHOUSE

Soil Type	Cut- ting	Yield of Alfalfa (grams per pot)				L.S.D. (05)
		No Lime	Cal- cium Car- bonate	Pul- verized Dolo- mite	Cal- cium Silicate Slag	
Brookston. .	1	7.19 ^a	7.59	6.68	7.64	N.S.
	2	7.37	7.67	8.41	7.96	N.S.
	3	6.96	7.88	9.01	8.05	N.S.
	Total	<u>21.52</u>	<u>23.14</u>	<u>24.10</u>	<u>23.65</u>	N.S.
Warsaw . . .	1	5.23	5.40	5.33	5.22	N.S.
	2	4.06	6.09	4.86	4.25	1.04
	3	7.16	8.24	7.50	8.08	N.S.
	Total	<u>16.45</u>	<u>19.73</u>	<u>17.69</u>	<u>17.55</u>	N.S.
Hillsdale . .	1	4.80	6.03	6.22	6.15	N.S.
	2	5.90	7.62	8.34	7.10	1.38
	3	8.91	11.09	10.20	9.25	N.S.
	Total	<u>19.61</u>	<u>24.74</u>	<u>24.76</u>	<u>22.50</u>	3.08
Fox	1	3.68	4.12	4.22	4.36	N.S.
	2	4.23	5.65	4.90	4.70	N.S.
	3	6.68	8.10	8.42	8.25	N.S.
	Total	<u>14.59</u>	<u>17.87</u>	<u>17.54</u>	<u>17.31</u>	N.S.
Kalkaska . .	1	1.52	1.97	3.15	2.85	1.13
	2	2.05	3.23	4.36	3.70	1.45
	3	3.40	4.98	5.81	5.41	1.41
	Total	<u>6.97</u>	<u>10.18</u>	<u>13.32</u>	<u>11.96</u>	3.53

^a All values represent the average of three replications.

a significantly higher yield than did all other treatments at the 5 percent level.

Data from the second cutting of alfalfa from the Hillsdale soil showed that the calcium carbonate and the pulverized dolomitic limestone gave significantly higher yields than the no-lime treatment. This was also true for the total yields.

The growth of alfalfa on four of the five soils used in this phase of the study is further illustrated by Plates 1, 2, 3, and 4. It is evident that the Kalkaska soil has given the greatest response to liming.

Phosphorus content and uptake of phosphorus by alfalfa. As indicated in Table XVII, liming tended to increase the phosphorus content of alfalfa, especially that grown on the soils of finer texture. Little difference occurred between the phosphorus content of the alfalfa grown on the calcium carbonate and pulverized dolomite treated soils, except in the case of the Warsaw loam where the phosphorus content was slightly higher where the pulverized dolomitic lime was applied. The phosphorus content of the alfalfa on the Hillsdale, Fox, and Kalkaska soils treated with calcium silicate slag was somewhat lower than that grown on these same soils treated with the other two materials.

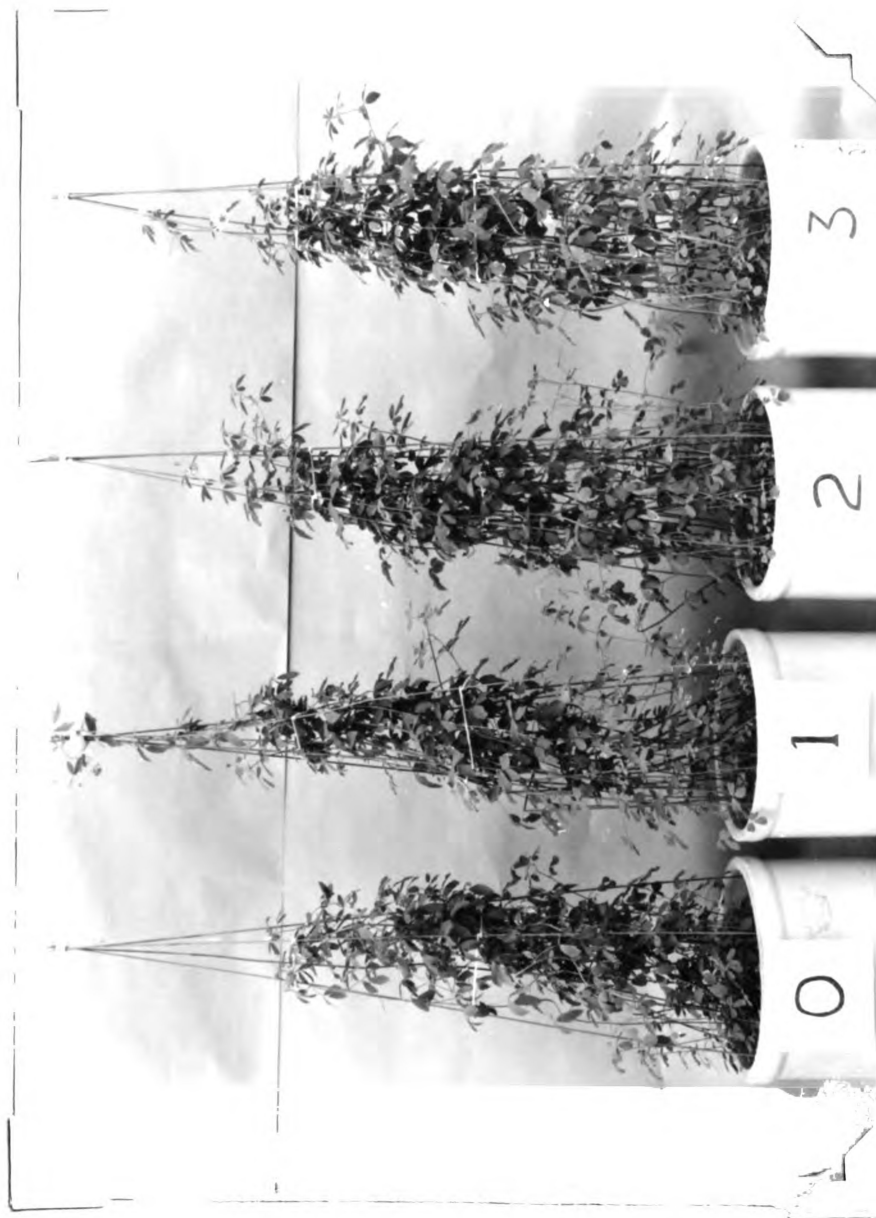


Plate 1. The effect of lime on the growth of alfalfa on a Brookston clay loam soil (0, no lime; 1, precipitated calcium carbonate; 2, pulverized dolomitic limestone; 3, water-quenched calcium silicate slag).

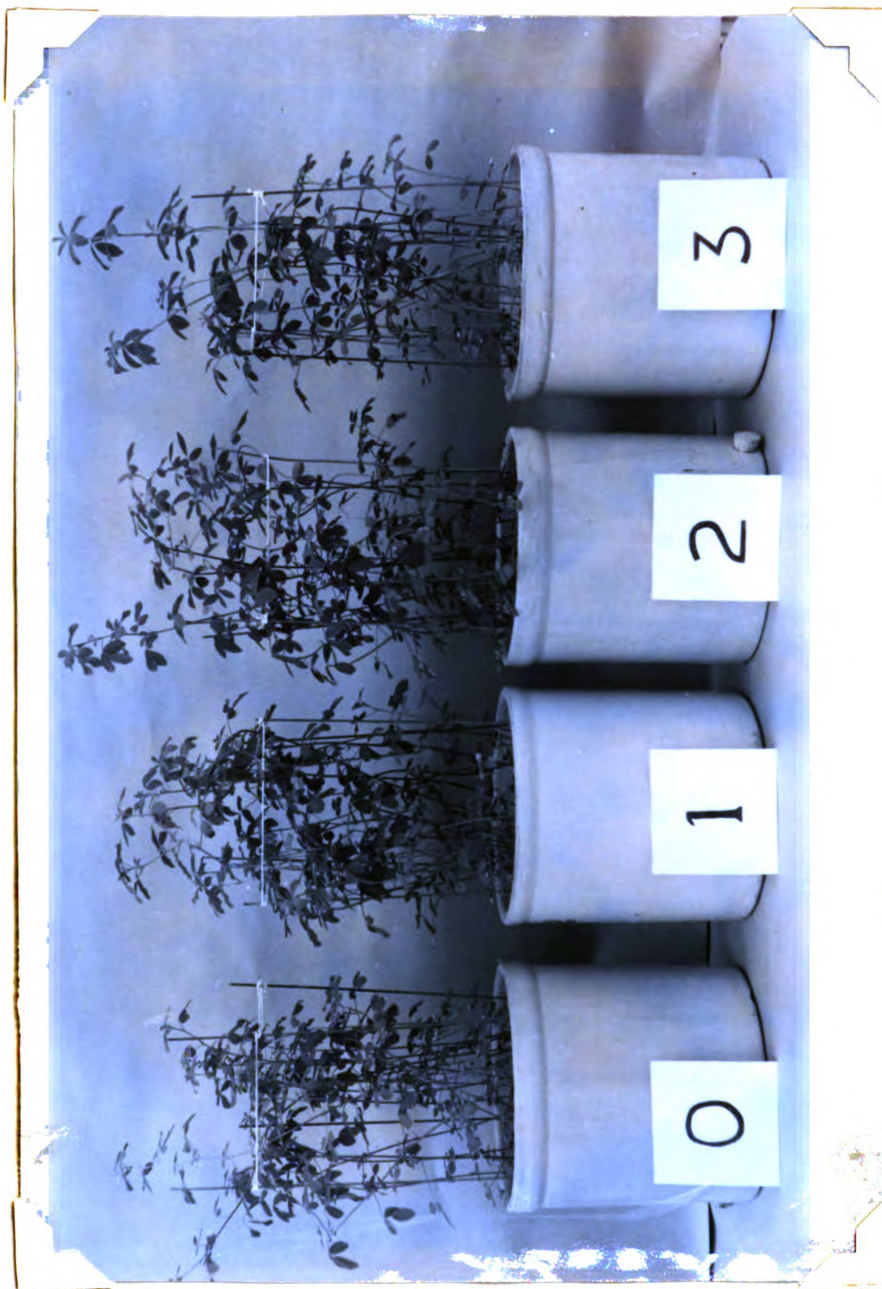


Plate 2. The effect of lime on the growth of alfalfa on a Warsaw loam soil (0, no lime; 1, precipitated calcium carbonate; 2, pulverized dolomitic limestone; 3, water-quenched calcium silicate slag).

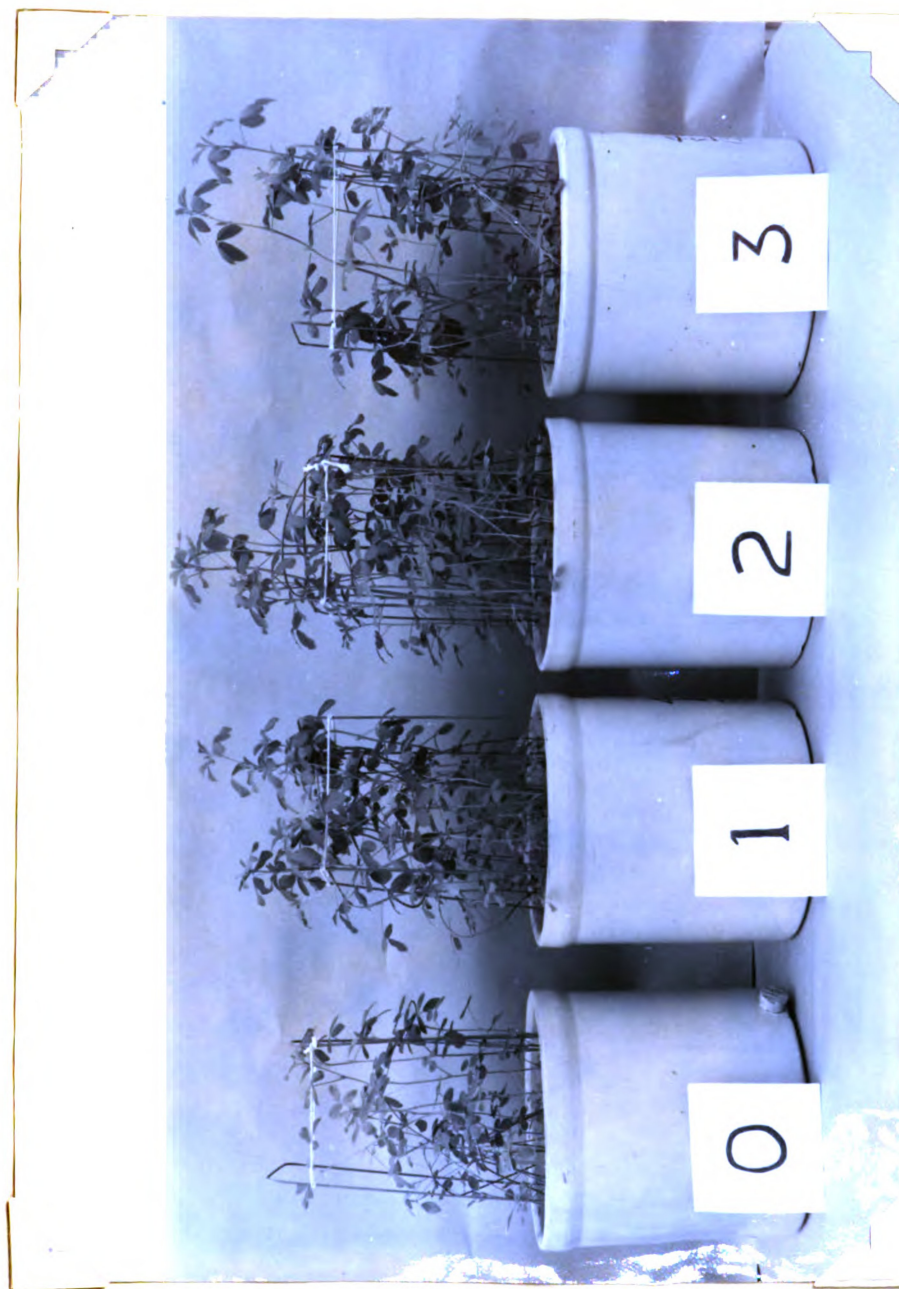


Plate 3. The effect of lime on the growth of alfalfa on a Hillsdale sandy loam soil (0, no lime; 1, precipitated calcium carbonate; 2, pulverized dolomitic limestone; 3, water-quenched calcium silicate slag).

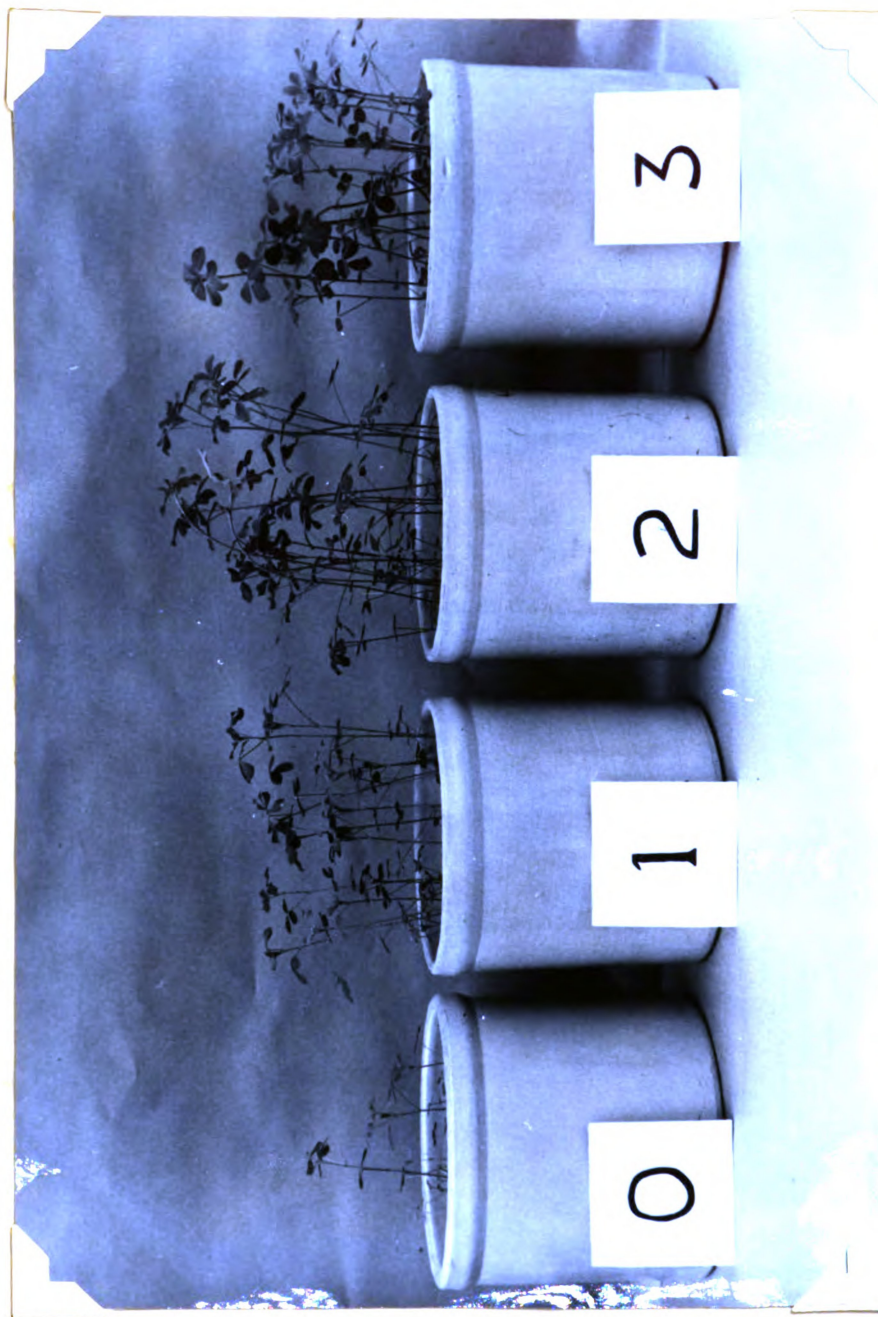


Plate 4. The effect of lime on the growth of alfalfa on a Kalkaska sand soil (0, no lime; 1, precipitated calcium carbonate; 2, pulverized dolomitic limestone; 3, water-quenched calcium silicate slag).

TABLE XVII

THE EFFECT OF THREE LIMING MATERIALS ON THE PHOSPHORUS CONTENT AND UPTAKE OF PHOSPHORUS BY ALFALFA GROWN ON FIVE GREENHOUSE SOILS

Soil Type	Cut- ting	No Lime	
		P Content ^a	P Uptake ^b
Brookston	1	2.565 ^c	18.44
	2	2.815	20.75
	3	2.440	16.98
	Avg.	2.607	18.72
Warsaw	1	2.465	12.89
	2	2.255	9.16
	3	2.030	14.54
	Avg.	2.250	12.19
Hillsdale	1	2.290	10.99
	2	1.755	10.36
	3	1.940	17.29
	Avg.	1.995	12.88
Fox	1	2.370	8.72
	2	2.390	10.11
	3	2.390	15.97
	Avg.	2.383	11.60
Kalkaska	1	2.230	3.39
	2	1.965	4.03
	3	1.665	5.66
	Avg.	1.953	4.36

^a Milligrams per gram.

^b Based upon the yield per pot of oven-dry alfalfa.

TABLE XVII (Continued)

Calcium Carbonate		Pulverized Dolomite		Calcium Silicate Slag	
P Content	P Uptake	P Content	P Uptake	P Content	P Uptake
2.815	21.37	2.540	16.97	2.780	21.24
2.790	21.40	2.815	23.67	2.690	21.41
2.280	17.97	2.280	20.54	2.230	17.95
2.628	20.24	2.545	20.40	2.567	20.20
2.605	14.07	2.615	13.94	2.505	13.08
2.140	13.03	2.465	11.98	2.280	9.69
1.915	15.78	2.140	16.05	2.190	17.70
2.220	14.29	2.407	13.99	2.325	13.49
2.755	16.61	2.020	12.56	2.655	16.33
2.380	18.14	2.840	23.69	1.990	14.13
2.780	30.83	2.865	29.22	2.290	21.18
2.638	21.86	2.575	21.82	2.312	17.21
2.770	11.41	2.590	16.11	2.555	11.14
2.465	13.93	2.520	12.35	2.265	10.65
2.390	19.36	2.520	21.22	2.290	18.89
2.542	14.90	2.543	16.56	2.370	13.56
2.165	4.27	2.255	7.10	2.180	6.21
1.855	5.99	1.830	7.98	1.540	5.70
2.465	12.28	2.370	13.77	2.005	10.85
2.162	5.64	2.152	7.21	1.908	5.69

^c All values represent duplicate determination on bulked replicates.

Lime considerably increased the total uptake of phosphorus by the alfalfa. The largest plant uptake of phosphorus on all soils was obtained using calcium carbonate and dolomitic limestone, with the exception of the Kalkaska sand. In this case, due to lower yields, the uptake of phosphorus by alfalfa from the calcium carbonate-treated soil was slightly less. The absorption from the calcium silicate slag-treated soils ranged from approximately the same as the other lime treatments to considerably less, depending on the soil type and the yield of alfalfa.

These results are in agreement with those found by MacLean (37) and others (2, 10). All of these investigators noted that increasing the pH of acid soils by the addition of lime increased the uptake of phosphorus by legumes.

Availability of phosphorus and potassium in the soil. As shown in Table XVIII, liming the Brookston and Kalkaska soils caused no significant change in the availability of phosphorus. At the 5 percent level of significance, the level of phosphorus, as measured by the Bray method, was lowered as a result of all lime additions to the Warsaw loam soil. At the 1 percent level, all treatments except the slag produced significantly lower amounts of available phosphorus. By the Spurway method, the dolomitic limestone and the slag treatments reduced phosphorus levels below those on the unlimed soil.

TABLE XVIII

THE EFFECT OF THREE LIMING MATERIALS ON THE AVAIL-
ABILITY OF PHOSPHORUS AND POTASSIUM
IN FIVE GREENHOUSE SOILS

Soil Type	Test	Prior to Treat- ment (lbs./A.)	No Lime (lbs./A.)
Brookston	Bray's P ^a	11.3 ^c	36.6
	Spurway's P ^b	47.5	73.0
	Spurway's K ^b	135.0	109.0
Warsaw	Bray's P	25.9	51.3
	Spurway's P	13.0	24.0
	Spurway's K	150.0	142.0
Hillsdale	Bray's P	45.8	94.3
	Spurway's P	23.0	39.3
	Spurway's K	144.0	105.0
Fox	Bray's P	21.7	50.9
	Spurway's P	19.0	33.7
	Spurway's K	138.0	85.0
Kalkaska	Bray's P	39.6	80.7
	Spurway's P	25.0	34.3
	Spurway's K	150.0	109.0

^a Bray's adsorbed phosphorus using 0.025 N HCl and 0.03 N NH₄F as the extracting solution.

^b Spurway's reserve test using 0.13 N HCl as the extracting solution.

TABLE XVIII (Continued)

Calcium Carbon- ate (lbs./A.)	Pulver- ized Dol- omite (lbs./A.)	Calcium Silicate Slag (lbs./A.)	L.S.D.	
			(05)	(01)
34.5	33.4	36.6	N.S.	
73.0	79.0	76.0	N.S.	
101.0	104.0	108.0	N.S.	
37.1	38.5	41.8	6.32	10.16
22.7	21.3	19.7	2.05	3.30
128.0	140.0	130.0	N.S.	
77.0	73.7	76.3	15.02	
48.7	41.5	37.7	6.45	
88.0	86.0	85.0	N.S.	
49.7	47.1	53.0	N.S.	
41.7	35.7	31.0	4.15	6.67
86.0	83.0	84.0	N.S.	
59.7	62.5	70.0	N.S.	
43.3	35.0	41.7	N.S.	
117.0	95.0	109.0	N.S.	

^c All values represent the average of three replications.

All lime applications significantly depressed the level of phosphorus in the Hillsdale sandy loam soil, as measured by the Bray method. By the Spurway method, the use of calcium carbonate resulted in a significant increase in phosphorus availability. This was also the case with the Fox soil using the same method for determining phosphorus.

None of the lime treatments produced any significant change in the availability of potassium in the five soils studied.

The trend toward a lower level of available phosphorus in some of these soils may be due to several factors. First, the presence of free carbonates in the soil has been suggested as an explanation for decreasing availability of phosphorus after liming (59). Secondly, the additional growth of alfalfa and subsequent uptake of phosphorus as a result of liming would tend to decrease the level of available phosphorus in the soil. Thirdly, the fact that the soil reaction actually exceeded the neutral point on most of the soils several months after applying lime would tend to decrease the amount of available phosphorus present. A pH of 6.5 has been found to give the maximum availability of phosphorus on the majority of soils (66).

Other investigators (21, 24) have noted that lime applied in moderate amounts to soil has little effect on the availability of

potassium, which is in agreement with the results of these studies, both in the greenhouse and in the field.

SUMMARY

Liming studies were conducted on three field soils and five greenhouse soils to determine the rate of change of soil reaction and changes in the content of exchangeable bases and percent base saturation resulting from the application of liming materials varying in source, grade, neutralizing value, and degree of fineness. Phosphorus and potassium determinations were made to determine availability changes brought about by liming.

On one of the soils, Warsaw loam, two dolomitic limestones varying only in their degree of fineness were applied at rates ranging from two to ten tons per acre. On the Hillsdale sandy loam soil, two pulverized dolomitic limestones were compared with a calcitic limestone meal, while on the Kalkaska sand, calcitic and dolomitic meals, pulverized dolomite, and water-quenched calcium silicate slag were compared. On these latter two soils, lime was applied in varying amounts calculated to give a desired pH level, based upon the lime requirement as determined by the Bradfield-Allison method (12).

Determinations for pH, exchangeable bases, percent base saturation, phosphorus by the Bray Adsorbed (14) and Spurway Reserve

(63) methods and potassium were made on soil samples taken at intervals following lime additions. Crop yields were also obtained.

In the greenhouse, equivalent amounts of three liming materials were applied to five soils; namely, Brookston clay loam, Warsaw loam, Hillsdale sandy loam, Fox sandy loam, and Kalkaska sand. The three materials, precipitated calcium carbonate, pulverized dolomitic limestone, and calcium silicate slag, were applied in amounts equal to the Bradfield-Allison lime requirement. Three cuttings of alfalfa were obtained from each pot culture for the determination of yield and phosphorus content. Soil samples were taken at two-month intervals after liming to determine changes in pH. Phosphorus and potassium determinations were made on the soil samples prior to the addition of lime and at the end of six months.

The results of these investigations may be summarized as follows:

1. Applying lime as a fractional part of the total lime requirement was not an accurate method of reaching a desired pH level.
2. A moderate to high degree of correlation existed between the lime requirement, hydrogen-ion concentration, and percent base

saturation prior to liming. This correlation was highest on the poorly buffered Kalkaska sand soil.

3. In the field, lime applications did not raise the pH the anticipated amount, while in the greenhouse, applications of lime equal to the lime requirement exceeded the theoretical values. This indicates that the use of an appropriate liming factor is necessary under field conditions in order to attain expected values.

4. Calcitic limestone meal increased the pH slightly more rapidly than did the corresponding dolomitic limestone meal. However, pulverized dolomitic limestone reacted more quickly with the soil than did either of the meals. The calcium silicate slag was somewhat slower in raising the pH than were the other materials studied.

5. One year after liming the differences in pH resulting from comparable rates of application of the various materials were very slight.

6. A moderate degree of correlation existed between decreasing hydrogen-ion concentration after liming and increasing content of exchangeable bases and percent base saturation for any particular soil. However, comparing all soils, wide variations occurred.

7. The amount of lime necessary to attain a desired pH, and the length of time required to reach this pH, was roughly

proportional to the exchange capacity and the original degree of acidity. The lower the exchange capacity and the greater the degree of acidity prior to liming, the faster the response to any given type of lime.

8. No significant correlation existed between changes in the availability of phosphorus and potassium and changes in the hydrogen-ion concentration under field conditions. There was a trend toward a decreased supply of available phosphorus after liming the greenhouse soils.

9. The highest rates of application, especially of pulverized dolomitic limestone, significantly increased the yield of sweet clover on the Kalkaska sand, but liming had no appreciable effect on the yield of wheat, corn, and oats grown on the Warsaw and Hillsdale soils. In the greenhouse, the total yield of alfalfa was significantly increased on the Hillsdale sandy loam by additions of calcium carbonate and pulverized dolomitic limestone, and on the Kalkaska sand by additions of dolomitic lime and calcium silicate slag. These were the two soils which had the lowest initial pH.

10. Lime tended to increase the phosphorus content and total uptake of phosphorus by alfalfa in the greenhouse. This trend was greatest where the calcium carbonate and pulverized dolomitic limestone were used.

11. The extreme variability to be expected from lime additions to any one soil type was indicated by the wide differences which were present between replications and between samplings.

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