THE EFFECT OF KIND, AMOUNT AND PARTICLE SIZE OF LIME ON REACTION, RESIDUAL CARBONATES AND EXCHANGEABLE CALCIUM, MAGNESIUM AND POTASSIUM IN AN ORGANIC AND A MINERAL SOIL

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Jacques R. Jorgensen

1957

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By

Jacques R. Jorgensen

AN ABSTRACT

Submitted to the College of Agriculture
of Michigan State University of Agriculture
and Applied Science in partial fulfillment of the requirements for the
degree of

MASTER OF SCIENCE

Department of Soil Science

1957

Approved R. L. Cook

Jacques A. Jorgensen

ABSTRACT

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Calcitic and dolomitic limestone were applied to the mineral soil at two, five and eight ton rates after being separated into finer than 200, 100-200, 60-100, 40-60, 20-40, and 8-20 mesh sizes. Similar particle sizes were used in applications to Rifle peat at three, six and twelve ton rates. Calcium hydroxide and precipitated calcium carbonate were also added to the soils in the same amounts. At intervals during a two month incubation period the soils were tested for reaction and residual carbonates. Before planting corn at the end of the incubation period to show the relationship between uptake of phosphorus fertilizer and lime, soils were tested for exchangeable calcium, magnesium, and potassium.

Soil acidity was found to decrease as the rate of application of lime was increased in both organic and mineral soils. One exception to this was where finer than 100 mesh calcitic limestones were applied to the mineral soil at five and eight ton rates. Calcitic limestone of 60-100, 100-200 and finer than 200 mesh were equally effective in raising soil pH over the two month incubation period, in contrast to the increasingly higher pH found where successively finer dolomitic stone was applied

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to mineral soil. Limestone particles larger than 60 mesh in size were ineffective as agents to correct soil acidity.

On mineral soil, calcitic limestone was more effective in correcting soil acidity than the dolomitic stone, though when applied to the organic soil both stones finer than 60 mesh were equally efficient. Breakdown of lime was more rapid in organic than in mineral soil, as shown by final pH and residual carbonates. In general, calcitic limestone reacted more quickly with the soil than dolomitic limestone.

Above a pH of 7.0 no exchangeable magnesium was found where calcitic liming materials had been applied to the mineral soil, though they had no effect on the exchangeable magnesium in the organic soil. The dolomitic stone caused an increase in the exchangeable magnesium as the rate of application increased and particle size decreased. Exchangeable calcium was found to increase with the rate of application of lime and the final pH of the soil. None of the treatments affected the amount of exchangeable potassium.

For unknown reasons, the plants grown on the mineral soil were deficient in phosphorus. The uptake of phosphorus fertilizer by these plants was not influenced by the differences in lime treatment. A reduction in fertilizer phosphorus uptake occured when twelve tons of lime were applied to the organic soil.

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ACKNOWLEDGEMENT

The author wishes to express his appreciation to Dr. K. Lawton for his advice, aid and encouragement during the investigation and in the preparation of this manuscript. He also wishes to thank Dr. J. F. Davis for his helpful comments on writing this paper.

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INTRODUCTION

Liming soils has been practiced ever since the early Romans recommended the use of manure and lime along with other "modern" farming practices. Thus far the effect of lime on the various chemical, physical and biological processes in the soil has been established, though sometimes not decisively. Due to the effect of lime on these processes it is desirable to know at what rate these changes may be expected to take place when a specific amount of lime is added to an individual soil, since the rate of these processes is dependent, to a certain extent, on the reaction rate of the limestone added.

With the increase in the use of lime in the last few decades new information is needed to supplement the experimental data now available on different kinds of liming material. To cite an example: If a farmer receives a recommendation that it will take five tons of lime to raise the pH of his soil to one most favorable for the crops he is growing, shall he apply calcium or dolomitic limestone, a limestone with a high neutralizing value; or will a larger amount of limestone with a lower neutralizing value give better results? Shall he apply coarse or fine limestone; and one of the most important questions, which combination of these choices will give the highest yields at lowest cost?

One of the aims of this experiment was to investigate the effect of composition, neutralizing value, rate of application, and fineness of several forms of lime on soil reaction, exchangeable calcium, magnesium and potassium, as well as the effect of lime on the uptake of

P^{32} by corn plants. The evaluation of liming materials was carried out by determining the change in hydrogen ion concentration and the amount of residual carbonates in the soil after liming.

Though a great deal of research work has been carried out on the relationship between the availability of phosphorus and potassium and soil pH as affected by liming, a large amount of this information is conflicting. As a supplement to this study of lime, its effect on the amount of exchangeable soil potassium and the uptake of applied phosphorus by plants grown in the greenhouse was also noted.

REVIEW OF LITERATURE

Lime, in the chemical sense, refers to only one compound - calcium oxide. However, agriculturally the term "lime" has a much broader meaning, and when used in this sense is defined by Lyon and Buckman (25) as a material that "includes all compounds of calcium and magnesium employed in a practical way not only to raise the pH of an overly acid soil but especially to rectify its physiological condition." The definition involves not only the change in hydrogen ion concentration, but also indicates lime is a material which alleviates the conditions associated with low pH.

Liming, as an agricultural practice has been used since before the Christian era. Truog (42) stated that lime was first recognized as a soil additive to control pH by workers in Rhode Island around the latter part of the 19th century.

Though liming has been shown to increase the growth of crops, there are differences of opinion among research workers as to the cause of the increase. Albrecht (1) has suggested that increased growth with lime is largely due to supplying formerly deficient plants with calcium. Other workers (31, 32, 37) reported that plant growth is reduced on acid soil because of the effect of active hydrogen, manganese, aluminum and other ions on the plant, and that lime added to the soil will reduce the hydrogen ion concentration and solubility of possible toxic materials.

Since the early writings of Edmund Ruffin (1794-1856), a Virginia agriculturalist, two schools of thought have existed on the principal use of lime, or calcium in the soil. Fried and Peech (20) found that plants were unable to absorb calcium from soils treated with gypsum, which left the soil acid even though there was plenty of exchangeable calcium. From this they concluded that poor growth of plants on acid soil is not necessarily due to lack of calcium, but may involve factors such as toxicity of manganese, iron and aluminum, the significance of which will vary from crop to crop. They also found that none of the gypsum treatments affected the uptake of phosphorus by the plants.

On highly weathered Putnam soils, Albrecht (1) applied limestones ranging from 10 to 100 mesh at rates of 300 to 4000 pounds per acre with a fertilizer drill. He found that the 10 mesh limestone gave higher yields of alfalfa than 100 mesh, and this was attributed to the slower delivery of calcium by the large particles and a resulting lower degree of calcium saturation. A slow steady delivery may be more important than saturating the soil with calcium since acidity causes weathering of the silt fraction, and, also, nutrients stored on clay can be released for plant use. From these findings Albrecht advances the theory that plant roots can reach out to the various areas of the soil and select the needed elements: Iron from an acid area, calcium from a neutral zone, or potassium from a feldspar particle.

Albrecht and Smith (2) stated that soil acidity is the natural result of crop production, and, as such, increases whenever fertility is permitted to decline. If the nutrients, particularly calcium, can be restored, the hydrogen ions can play an important part in increasing the availability of mineral reserves in the silt fraction and promoting their absorption. An additional factor limiting growth on acid soils may be injurious conditions resulting from an accumulation of hydrogen ions around root hair cells when they can no longer be exchanged for other cations in the environment.

In a study at Iowa State College by Dean (16) it was found that initial rate of reaction of calcium limestone was higher than dolomitic limestone, though at the end of a five month period no large differences occurred in moisture content, pH, total exchangeable bases, cation exchange capacity, degree of calcium saturation, nitrate content, and nitrifying power when different liming materials were applied. In a precautionary note, they commented that the addition of magnesium as dolomitic limestone to a soil already high in magnesium may have a toxic effect on plants. Finer limestones, it was found, were more effective in reducing the hydrogen ion concentration but had les nitrifying power than coarse limestone.

Other Iowa workers, Dean and Walker (17), added both calcium and magnesium limestone to soil. There was no difference in their effect on pH of the soil under similar conditions where ample time was given to allow reaction, though the calcium limestone decreased the hydrogen ion concentration more rapidly. They also found that exchangeable calcium was increased as the amount of lime applied increased, and that the calcium limestone increased calcium saturation more than the dolomitic limestone. The addition of calcium limestone had little effect on the amount of exchangeable soil magnesium, as was the case for soils treated with the magnesium limestone - at least for the first three months. However, after this initial period there was an appreciable increase in exchangeable magnesium up to the sixth month when dolomite was applied. It was also shown that magnesium limestone was not as effective as the calcium variety in stimulating nitrification in the soil, especially in the first three months. However, these workers concluded that over a longer period of time there would be little difference between these limestones.

Meyer and Volk (26) found that as the rate of application and fineness of liming material increased the exchangeable calcium also increased. Soils treated with calcitic limestone, though showing an increase in exchangeable calcium, became lower in exchangeable magnesium as the fineness of the particles increased. The use of dolomitic limestone generally increased both exchangeable calcium and magnesium as fineness and amount applied increased.

Perhaps the most thoroughly investigated phase of liming and soil acidity as related to nutrient availability involves phosphorus. Salter and Barnes (35) noted that lack of response to superphosphate by crops grown under slightly neutral conditions created by liming was largely due to an increase in native soil phosphorus on liming so that plants required no additional phosphate fertilizer. Beater (7) found that increasing pH to certain levels with lime prior to planting resulted in a twenty percent increase of phosphorus in the plant. This agrees with the findings of Davis and Brewer (15), who, in their work on four Louisiana soils, reported that a deficiency of calcium limited the normal uptake of phosphorus by plants.

Somewhat at variance with the above conclusions are those of Scarseth and Tidmore (36), whose findings showed that calcium carbonate decreased the availability of phosphates. This effect decreased with the length of time the calcium carbonate was present in the soil. When free carbonates were no longer present the availability of the phosphates increased. It was thought that hydrolysis of the calcium carbonate and bicarbonate in the soil solution caused the calcium to unite with the soluble phosphorus to form relatively insoluble dicalcium or tricalcium phosphate. When all the calcium carbonate was incorporated into the soil the phosphorus was available for plants.

Cook (13) in working with several Michigan soils was able to show that increasing the base saturation resulted in significant increase in the amount of readily available phosphorus in seven soils with slight increases in two others. The availability of the soluble phosphates was also preserved by lime.

The presence of an excess of calcium in the carbonate, hydroxide or oxide forms may cause the formation of a more basic salt than tricalcium phosphate; and Naftel (28) postulated that this was hydroxy apatite ($3Ca_3(PO_4)_2 \cdot Ca(OH)_2$). Magnesium phosphates, when formed, are similar to calcium, though less soluble. He also found that calcium had no effect on the sorption of phosphates by colloids with low SiO_2 / R_2O_3 ratio, but for those with high ratios the sorption of phosphorus was increased. The conclusion then is, that liming acid soils will cause a decrease in phosphorus by increasing the phosphorus sorption by soil colloids only on soils that have high SiO_2/R_2O_3 ratios. Naftel also noted that calcium phosphates begin to precipitate at a pH of about 6.5.

Results similar to those of Naftel were observed by Robertson, Neller and Bartlett (34), who found that liming of soils low in phosphorus increased phosphorus up to a pH of 6-6.5 when sesquioxides were high, but had no effect when sesquioxides were low. Above pH 6-6.5 the percent of phosphorus in the plant decreased, probably due to the formation of tricalcium phosphate. Liming soils high in phosphorus reduced the uptake of plants whether sesquioxides were high or low, and uptake of phosphorus was highest from soils with high sesquioxide content, irrespective of liming rate.

Neller (29) treated soil with 500 to 1500 pounds of lime per acre so that pH was from 5.4 to 6.8. He found lime caused a reduction in the phosphorus content of plants growing in Rutledge fine sand by the conversion of monocalcium phosphate to dicalcium phosphate or calcium fluorophosphate. Lime had an opposite effect on Marlbro fine sand, probably due to the large amounts of aluminum and iron in the soil which would form insoluble phosphorus compounds, but with the addition of lime formed more soluble calcium phosphate compounds.

Working with several Michigan soils, Pretty (33) found no significant correlation between the rate of application of lime and the chemical availability of phosphorus and potassium as measured by rapid soil tests. Dean (18) applied calcium carbonate, calcium chloride and calcium hydroxide to Tama silt loam and found that they replaced potassium and increased the amount of available potassium in the soil exchange complex. Calcium chloride in this experiment was most efficient and calcium carbonate the least efficient in releasing potassium. These findings agree with those of Opitz, et al. (30), who applied lime to sandy nutrient deficient soil and found increased exchangeable, citric acid and water soluble potassium.

York and Rogers (46) observed calcium added to soils resulted in an increased release of non-exchangeable potassium on every soil studied, though the amount of potassium released on some of the coarse textured soils was small. They found it difficult to generalize as to the over-all influence of lime on the supply of available potassium. For instance, an addition of lime could either increase or decrease the potassium depending on its availability, ability of the soil to fix applied potassium, and on the solubility of potassium minerals in the soil.

Hartwell and Damon (21) cropped plots to which lime of different particle size had been added and found that less than 80 mesh limestone was mot effective in increasing yields for the first three years. Yields for the fourth and fifth years, however, were highest where the coarser grades had been applied. These results would lead one to believe that the finer limestone reacted more quickly with the soil, and thereby were able to stimulate plant growth earlier than a coarser grade.

As early as 1917, White (44) added high calcium and high magnesium limestones of various fineness to soil and allowed them to react for a period of three years. After this period it was found that over ninety per cent of both the 100 mesh magnesium and calcium limestone had reacted. In the same amount of time, only six percent of the 8 mesh magnesium, and 14.9 percent of the 8 mesh calcium limestone, had reacted. Limestones of 60 and 20 mesh decomposed intermediately between the coarse and fine grades. Generally the high calcium limestone decomposed faster than those containing magnesium. Ames and Schollenberger (3) observed similar results over a sixteen month period, whereupon the calcium limestone had a faster initial reaction; though by the end of the period the finer magnesium stones had decomposed as much as the calcium stone.

Bear and Allen (5) reported that all factors being equal, the rates of solution of different sized particles should be proportional to the surface exposed to the solvent; thus all surfaces should be dissolved at equal rates. A formula for the comparison of the rates of reaction of various sized particles has been developed by the authors: $\frac{D^3 - (D-d)^3}{D^3}$, presuming that both particles are the same shape, and where D equals diameter of large particle and d equals diameter of the small particle. The result gives the percent of the larger particle dissolved when the smaller is completely dissolved. To test this assumption, they added 2,958 pounds per acre of 48-65 mesh calcium limestone having a neutralizing value of 93 percent to plots. This amount and mesh were chosen on the basis that this size particle would be completely dissolved in twelve months. Enough of the coarser limestone was added per acre so that in twelve months, theoretically, a quantity equal to the 48-65 mesh would go into solution. After the twelve month reaction period the soils were analyzed for residual carbonates. By determining the amount of carbonates that had gone into solution, the actual efficiency could be compared with that proposed by the formula. It was found that particles larger than twenty mesh had an actual efficiency only about fifty percent that of the theoretical efficiency. The size fractions smaller than twenty mesh had actual and theoretical efficiency values nearly equal. Bear and Allen believe that one reason for the slow solubility of the large particles is that as their size increases diffusion plays an increasingly important part in their solution.

Dolomitic limestone was used with fertilizer at a rate of 1,333 pounds per acre on several crops. After 75 days the crops were harvested. At this time Collins and Speer (12) measured the amount of residual carbonate, and found the following amounts of each had decomposed: 20-40 mesh, 27.5 percent; 40-60 mesh, 46 percent; 60-80 mesh, 60 percent; 80-100 mesh, 65.9 percent; 100-200 mesh, 78.2 percent; and through 200 mesh 87.3 percent. Soils high in organic matter showed a lower increase than those that were low due to buffering and decomposition of organic matter.

Bear and Toth (6) mixed limestone that passed 100 mesh with moist soil, at a rate of two tons per acre and tested them weekly. Highest pH values were generally reached in one week, and then fell for the following four weeks due to nitric acid being formed by decomposition of organic matter. Additional work was done by adding seven tons of various sizes of calcitic limestone per acre to a loam soil, and noting the pH at intervals of time. Generally there was an increase in pH with a decrease in particle size over the three week reaction period. Soil to which hydrated lime had been added had its highest pH immediately after application, with a rapid reduction the first day, and a more gradual reduction throughout the three week period. From this observation Bear and Toth estimated that limestone particles passing through a 150 mesh screen onto a 200 mesh are all dissolved in the soil after two weeks, while 87.5 percent of a 65-150 mesh, 33.2 percent of 20-28 mesh, and 17.8 percent of a 10-14 mesh product, decomposed.

Meyer and Volk (26) working with uncropped soils in pots found liming particles coarser than 20 mesh had little or no value in correcting soil acidity. Liming materials ranging in size from 20 to 60 mesh had little initial soil reaction, but after 18 months were as effective as finer sized fractions. Particles smaller than 100 mesh reacted soon after application, but decreased in effectiveness after 18 months. Calcitic limestone was slightly more effective than dolomitic limestone in correcting soil acidity; however after nine months dolomitic limestone finer than 50 mesh resulted in higher pH values of soil. In this study crop response was found to be dependent on the percentage of material finer than 40 mesh for initial correction and maintainance of a favorable soil reaction. These Ohio workers concluded that 4-8 mesh limestone has little or no value as a liming material, whereas 20-30 mesh material may become effective over extended periods. In order for lime to be effective within a year, a large proportion of limestone must be finer than 40 mesh.

The effectiveness of limestone as a soil amendment depends on two properties of the material; first, the capacity to neutralize soil acidity, and, second, the rate at which the material will react with the soil to accomplish neutralization. Of these two properties, rate is more difficult to measure. two methods for measuring reaction utilizing radiochemical techniques have been reported by Smith, Blume, and Whittaker (39). One method involves adding limestone to a soil whose calcium has been labeled with Ca^{45}, followed by an isotopic analysis of successive crops grown thereon. The other method involves measurement of Ca^{45} and Ca^{40} concentrations in dilute calcium nitrate solution before and after equilibrium with soil previously treated with limestone. The specific activity of the solution during equilibrium with the sample can then be measured. In their experiments, these workers found that 170-200 mesh and 80-100 mesh limestone completely reacted in 49 days, while the coarser particles took longer. Most reaction occurred the first few days, with the smaller particles reacting faster - a conclusion reached by most previous workers.

EXPERIMENTAL PROCEDURE

Two soils, one organic and one mineral, were used in this study. The organic soil was a rifle peat from the Lansing, Michigan, airport area, not now in cultivation. The mineral soil, a sandy loam, was obtained from the Graham Horticultural Station near Grand Rapids. Some physical and chemical characteristics of these soils are shown in Table I.

Both soils were prepared for use by sieving through a half-inch mesh screen after air drying the mineral soil, and allowing the organic soil to reach a workable moisture content from its previously saturated condition. One gallon tin cans with solid bottoms were used to hold 4070 grams of mineral soil, or 1900 grams of the organic soil.

Dolomitic limestone, high calcium limestone, precipitated calcium, calcium carbonate, and calcium hydroxide, were the four liming materials added to the soils. To the organic soil lime was applied at rates equivalent to 0, 3, 6, and 12 tons of calcium carbonate per acre, while the mineral soil received 0, 2, 5, and 8 ton rates. These amounts were decided upon somewhat arbitrarily. Soil and lime were mixed by dumping out the weighed amount of soil, adding the calculated amount of lime and mixing until the lime and soil were thoroughly blended. Each of the treatments were carried out in triplicate. After mixing the soils were brought to a moisture content about 25 percent above the moisture equivalent and covered with heavy paper to prevent evaporation. Additional distilled water was added at intervals to maintain moisture.

Table I. Some physical and chemical properties of the soils used in this experiment.

Property	Mineral	Organic
Mechanical analysis (hydrometer)		
Sand (2.0 - 0.02 mm) percent	65.7	
Silt (0.02 - 0.002mm) percent	23.0	
Clay (below 0.002mm) percent	11.3	
Organic matter content, percent	2.51	89.62
Moisture equivalent, percent	14.85	95.16
Cation exchange capacity, m.e. per 100 grams	5.16	147.19
Exchangeable potassium, pounds per acre	120	64
Exchangeable magnesium, pounds per acre	very low	526
Exchangeable calcium, pounds per acre		
Versenate method	395	684
Flame photometer method	300	980
pH (glass electrode)	4.15	4.25

The limestones were run through a series of sieves and separated into 8 - 20, 20- 40, 60 - 100, 100 - 200, and less than 200 mesh sizes. Neutralizing value, determined in duplicate, of each of the high calcium limestone mesh sizes was used as a basis for their addition to the soils. An average neutralizing value of the different mesh sizes was used as a basis for calculating the amount of dolomitic limestone to be added. Data on the lime and amounts added to the soil are found in Table II.

After the soil and lime were mixed, samples were taken from the cans with a soil sampling tube and the replicates of each treatment mixed together. Of this sample about fifty grams was spread on paper toweling to air dry, and the remainder was replaced approximately equally in each of the three cans. The dried soil was tested for pH, and in some cases, carbonates. Time between samplings varied according to material and mesh size, with the finest material sampled daily, until partial pH equilibrium was reached, and the coarsest tested at two to four week intervals.

Before planting a crop, the amounts of soil in each of two pots from each given treatment we readjusted so that they contained approximately the same volume of soil as when lime had first been added. Fifty pounds of nitrogen, as ammonium nitrate, one hundred pounds of K_2O as potassium chloride, and one hundred pounds of P_2O_5, as concentrated superphosphate labeled with P^{32}, were added per acre to each of the cans to assure a supply of nutrients. These fertilizers were blended with the soil in a rotary mixer.

On June 23 six corn seeds per can were planted in two replications of each treatment. As the plants emerged a severe magnesium deficiency was noted on those growing in mineral soil, and a spray of magnesium sulfate was applied to all plants on both mineral and organic soils. An additional fifty pounds per acre of nitrogen fertilizer was added as a solution on July 17 to correct a nitrogen deficiency.

Shortly after germinating, the corn plants were thinned to three per pot. The first plant sampling for determination of P^{32} uptake was made two weeks after planting. The above ground portion of one plant from each of the two replicates was harvested, combined and dried at 60° C. This plant material was then ground in a Wiley mill and analyzed for specific activity. At the second sampling the remaining plants were harvested four weeks after planting, and these samples were treated in the same manner as those sampled earlier.

Determination of exchangeable magnesium, calcium and potassium was made on soil from the third replicate of each treatment that was not planted to corn.

Table II. Some characteristics of the liming materials used in the incubation experiment.

Type of lime	Mesh	Neutralizing value	Rate of application[1]	Grams of lime per pot
$Ca(OH)_2$	200	135	2 tons per acre	6.06
			3 "	8.89
			5 "	15.14
			6 "	17.78
			8 "	24.25
			12 "	35.57
$CaCO_3$	200	100	2 "	8.16
			3 "	12.24
			5 "	20.40
			6 "	24.48
			8 "	32.64
			12 "	48.96
Dolomitic limestone	8- 200	102.97	2 "	7.94
			3 "	11.65
			5 "	19.86
			6 "	23.30
			8 "	31.78
			12 "	41.61

[1] Calcium carbonate basis.

Table II (continued)

Type of lime	Mesh	Neutralizing value	Surface area/gram[2]	Rate of application[1]	Lime grams/pot	Surface area of lime/pot
Calcitic limestone	8-20	88.35	1.00	2 tons/acre	9.26	9.26
				3 "	13.58	13.58
				5 "	23.16	23.16
				6 "	27.17	27.17
				8 "	37.05	37.05
				12 "	54.34	54.34
Calcitic limestone	20-40	84.93	3.48	2 "	9.63	33.51
				3 "	14.13	49.17
				5 "	24.09	83.83
				6 "	28.26	100.53
				8 "	38.54	134.04
				12 "	56.52	201.06
Calcitic limestone	40-60	79.80	10.73	2 "	10.26	110.09
				3 "	15.04	161.38
				5 "	25.63	275.01
				6 "	30.07	330.27
				8 "	41.00	440.36
				12 "	60.14	660.54

Table II (continued)

Type of lime	Mesh	Neutralizing value	Surface area/gram[2]	Rate of application[1]	Lime grams/pot	Surface area of lime/pot
Calcitic limestone	60-100	78.30	17.37	2 tons/acre	10.45	181.52
				3 "	15.32	266.11
				5 "	26.12	453.70
				6 "	30.65	544.56
				8 "	41.79	726.08
				12 "	61.30	1089.12
Calcitic limestone	100-200	82.52	23.97	2 "	9.92	237.78
				3 "	14.54	348.52
				5 "	24.79	594.22
				6 "	29.09	713.34
				8 "	39.67	951.12
				12 "	58.18	1426.68
Calcitic limestone	200	82.52	32.58	2 "	9.92	323.29
				3 "	14.54	474.71
				5 "	24.79	807.66
				6 "	29.09	969.87
				8 "	39.67	1293.16
				12 "	58.18	1939.74

[1] Calcium carbonate basis. [2] 8 - 20 mesh limestone taken as unity.

METHODS OF ANALYSIS

Lime

Neutralizing value of limestone was determined by boiling a five-gram sample of lime in 60 milliliters of 2 N hydrochloric acid and refluxing for 30 minutes. The solution was then diluted to 250 milliliters, and 50 milliliters aliquots were titrated with N sodium hydroxide.

Relative surface areas of calcium limestone particles were determined by a method developed by Barnes (4). Thomas and Gross (40) found variations in the surface area when limestones were reacted with oxalic acid as used in Barnes' method. Dolomitic limestone was found to react continuously with oxalic acid forming no surface coating and surface area could not be estimated. The same results were obtained with dolomitic limestones used in this experiment.

Each of the determinations on lime were done in duplicate or triplicate.

Soil

Exchange capacity of mineral soil was determined by a method similar to that of Schollenberger and Simon (38). Twenty-five grams of air dry soil were soaked in 250 milliliters of N neutral ammonium acetate for one hour and then filtered through a Buchner funnel. The soil was then washed with 95 percent ethyl alcohol until the filtrate no longer gave a test with Nesslers reagent. This filtrate was discarded. The soil was then leached with 200 milliliters of ten percent sodium chloride and the filtrate placed in Kjeldahl flask along with 20 milliliters of 2 N sodium hydroxide. By distilling this filtrate into 50 milliliters of four percent boric acid and titrating the distillate with 0.1 N hydrochloric acid, using bromcresol green as an indicator, the exchange capacity can be determined.

Exchange capacity of the organic soil was determined by using the method of Mortland and Mellor (27). This procedure was modified such that the soils were soaked for eight hours in barium chloride - triethanolamine solution instead of four. After washing, the soils were allowed to stand for 48 hours in alcohol - water solutions. Sample sizes ranged from 1.5 to 2.5 grams of air dry soil.

Exchangeable calcium and potassium were extracted with ammonium acetate and determination of these ions followed the procedure of Toth and associates (41). Twenty-five grams of oven dry mineral soil was soaked in 250 milliliters of ammonium acetate solution for one hour and then filtered. Due to the time required to wet organic soils, they were soaked for three hours before filtering. The filtrate was then used for exchangeable calcium and potassium determinations. Calcium was determined on the Beckman Model DU Quartz Spectrophotometer, and potassium on the Perkin-Elmer Model 52 A flame photometer. Vuirinen and Makitie (43) found that when using the Beckman instrument aluminum and magnesium caused negative errors in the calcium values, while potassium and sodium caused positive errors. Bower and associates (9) report ammonium acetate has a solvent action on calcarious material and may give higher readings for exchangeable calcium than would otherwise be expected.

Exchangeable calcium was also measured by the versenate method of Cheng and Bray (10) in conjunction with the determination of exchangeable magnesium. Oven dry mineral soils were extracted with 23 percent sodium nitrate, but due to difficulty in wetting organic soils, the ammonium acetate extracts were used. Solutions for titration were prepared by evaporating ammonium acetate filtrates, and then ashing them at 950 degrees C. for 20 minutes. The residue was then dissolved with a minimum of 0.1 N hydrochloric acid, brought up to volume and aliquot portions titrated as with the mineral soil. Several authors have called attention to difficulties encountered in the versenate method. Cheng, Melsted and Bray (11) give a method for removing interfering manganese, copper, and magnesium ions by the use of sodium diethyldithiocarbamate and isoamyl alcohol. Wilson (45) working with leaves noted that 0.1 percent of phosphorus in the samples caused a delay in the endpoint, while a 0.25 percent concentration made the endpoint in the titration so indistinct as to be of little value. The magnesium determination, Wilson found, lacked precision due to long titrations and accumulation of errors, though most of his results came within 15 percent of oxine values. As a correction he suggests that calcium be removed with oxalate and the solution then be titrated for magnesium with versenate. Several other authors reported magnesium ions interfere with the color change of the calcium indicator and that orthophosphate will precipitate calcium at the pH of the titration. No steps were taken to correct these effects in the calcium and magnesium determinations of the soils in the current study.

Soil reaction was determined with the Beckman Model H-2 glass electrode pH meter. Measurements involving organic soils were made with 1:2 water soil ratios: 15 milliliters of soil and 30 milliliters of water. The mixture was soaked for five minutes with intermittent stirring, after which a reading was taken. Hydrogen ion concentration of the mineral soils was measured using 20 grams of dry soil in 20 milliliters of water, the suspension being stirred for one minute. When readings were delayed on mineral soils for five minutes the pH increased one to two tenths of a pH unit. This increase was approximately the same as obtained after standing for fifteen minutes. The pH of organic soils increased approximately the same amount when left to soak fifteen minutes. It was believed that this increase is due to solution of carbonates.

Carbonates in the soil were determined by the method of Erickson, Li, and Gieseking (19). If the approximate amount of carbonate in the soil is known in advance the amount of soil to be reacted can be adjusted to give at least ten milligrams of carbon dioxide. Enough water should be added to the soil in each case so that there will be sufficient liquid to cover all soil particles completely; this is especially true in working with organic soils.

Plants

To obtain uniform samples for radioactivity measurements, one-half and one gram samples of dried plant material were pressed into pellets approximately three-quarters of an inch in diameter, with a Carver press using 12,000 pounds pressure per square inch. The specific activity of these pellets was measured on a Nuclear Measurements Decade Scaler Model DS-1 with a mica window tube. Activity counts were made for one minute and in most cases five runs were made, with the average of the two closest used for calculating the P^{32} uptake. Standard pellets containing 0.0240 grams of P_2O_5 as P^{32} labeled concentrated superphosphate per gram of plant material were made for comparison with unknowns.

RESULTS AND DISCUSSION

Soils

Mineral Soil

Two tons of lime per acre. The effect of particle size on rate of reaction where liming materials were applied in amounts equivalent to two tons of calcium carbonate per acre is given in Table III and Figure 1. Generally, the final pH of soil treated with calcitic limestone smaller than sixty mesh was approximately the same, between 5.8 and 5.9. Highest increase in pH per unit of time occurred during the first few days after the lime was added to the soil. Calcium hydroxide increased the pH from 4.2 to 5.8 within a 24 hour period. However, 59 days later the pH decreased to 5.2. This decrease may have been caused by the decomposition of organic matter and the resulting formation of nitric acid. Precipitated calcium carbonate reacted similarly to the calcium hydroxide, with the highest pH attained within the first few days of incubation and decreasing thereafter. The larger size fractions, those greater than sixty mesh, were less effective in changing pH, though possibly if the incubation period had been extended the 40-60 mesh material would have increased the pH to that reached when the finer particles were used.

Though each of the limestones was added in amounts that would result in equal neutralizing value, the speed of reaction is governed to a large degree by the surface area of the particles. The larger particles, though having the neutralizing power of the finer material,

Table V. The effect of kind of lime and particle size on pH, residual carbonates, exchangeable calcium by two methods, magnesium and potassium when applied to a sandy loam soil.[1]

Mesh size	Days of incubation	Tons of residual carbonates per acre[2]	Final pH	Pounds of exchangeable cations per acre: Calcium, Photometer[3]	Calcium, Versenate[4]	Magnesium	Potassium
			Calcitic limestone				
200	60	5.3	7.1	3,400	2,735	*	112
100-200	52	5.0	7.1	3,080	2,590	*	112
60-100	68	2.9	6.9	3,280	2,550	30	112
40-60	60	3.9	6.8	3,160	2,340	125	112
20-40	60	7.3	6.2	2,480	1,945	85	112
8-20	68	9.2	4.6	920	605	100	112
			Dolomitic limestone				
200	60	5.2	6.5	1,600	1,125	570	112
100-200	52	4.3	6.1	1,320	1,150	452	112
60-100	67	6.4	6.0	800	1,040	415	100
40-60	59	6.0	5.6	1,160	802	342	128
20-40	67	6.9	4.8	820	595	245	116
8-20	67	2.6	4.4	500	290	*	124
			Calcium hydroxide				
200	60	-	7.8	4,160	2,860	*	112
			Calcium carbonate				
200	59	4.7	7.3	-	2,330	*	120

[1] Original soil pH 4.2. Lime added to soil equivalent to eight tons of calcium carbonate per acre.

[2] Calcium carbonate basis.

[3] Soil extracted with 1N neutral ammonium acetate for one hour.

[4] Soil extracted with 23 percent sodium nitrate for two minutes.

* No endpoint observed in titration.

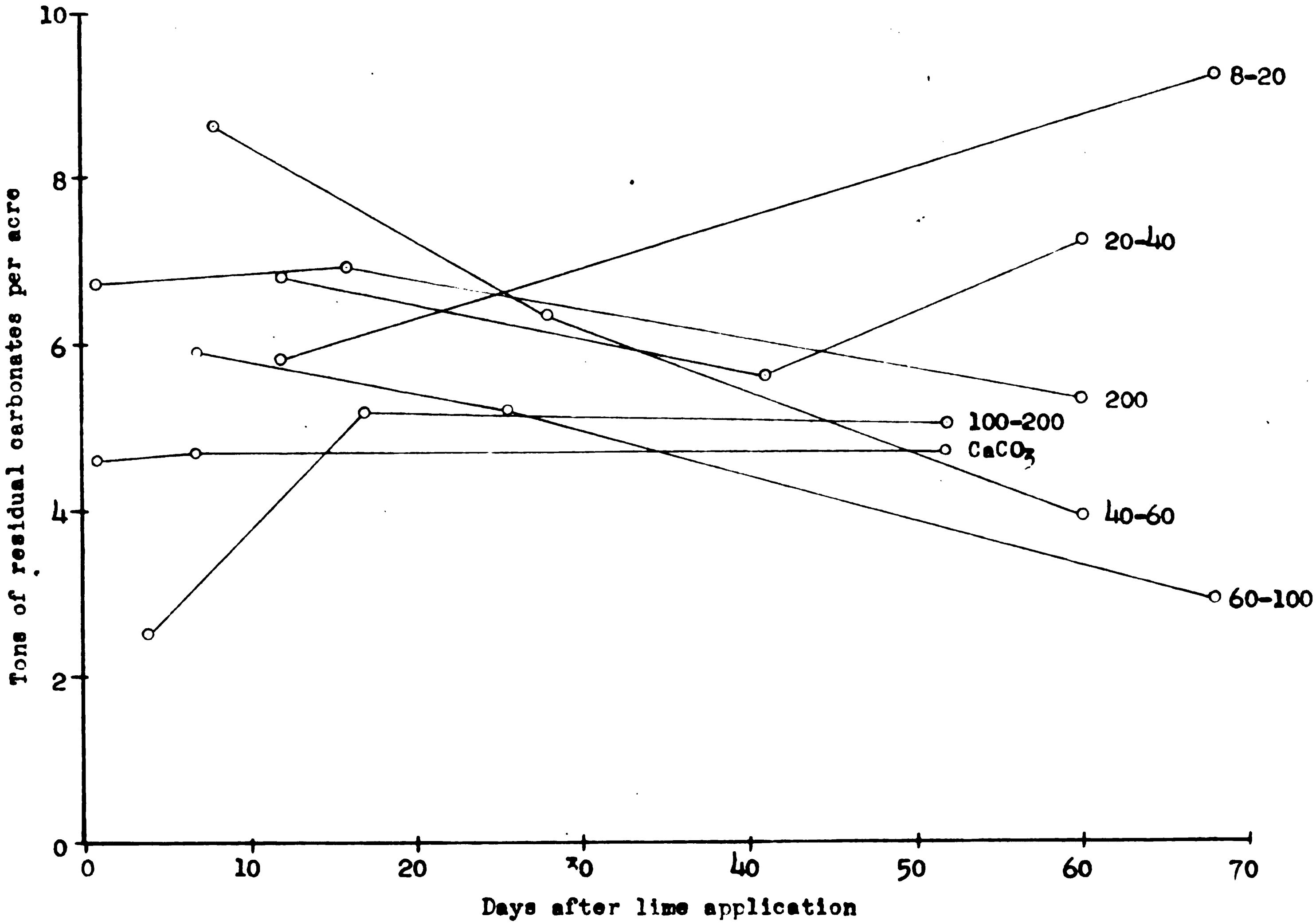

Figure 7. The effect of particle size (mesh) on amount of residual carbonates where calcitic limestone and precipitated calcium carbonate were applied to a sandy loam soil at a rate equivalent to eight tons of calcium carbonate per acre.

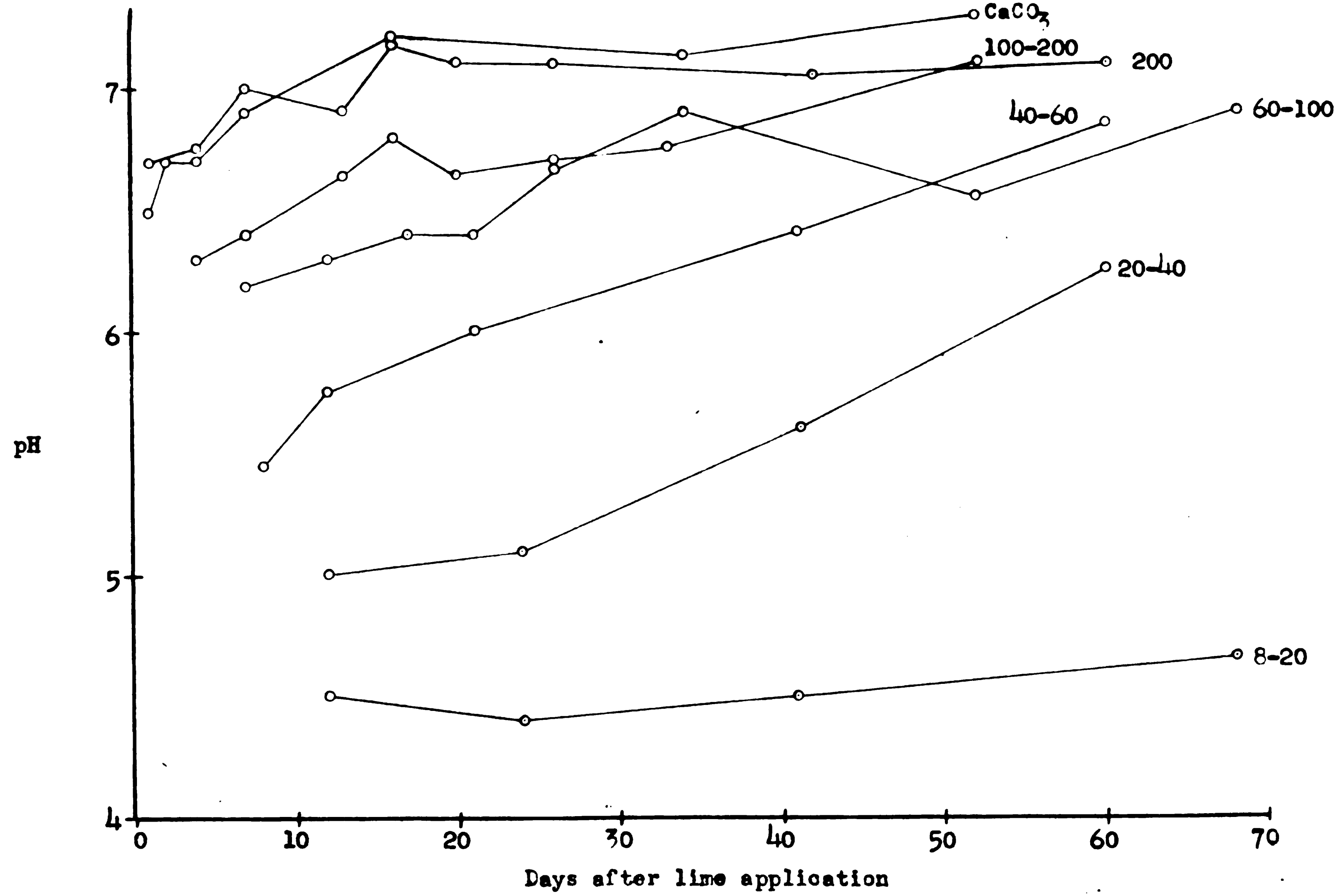

Figure 8. The effect of particle size (mesh) on change in the soil reaction where calcitic limestone and precipitated calcium carbonate were applied to a sandy loam soil at a rate equivalent to eight tons of calcium carbonate per acre.

cannot react as quickly due to their small surface area, which theoretically governs the rate of solution. Bear and Allen (5) reported that the rapidity of solution for larger particles is in part dependent on diffusion.

Dolomitic limestone was less effective in neutralizing soil acidity during the incubation period than the calcitic limestone. Only the less than 200 mesh material came close to being as effective as the finer grades of the calcium stone. Material larger than 60 mesh did not raise the soil pH above 5.0, and the 8-20 mesh stone had no apparent effect on pH. The difference between the neutralizing effect of the dolomitic and calcitic limestones is due to the greater solubility and surface area of the calcium stone as compared with that of the dolomitic material. As with the calcitic limestone, the greatest reaction of dolomitic limestone with soil occurred within the first few days after its application. This is illustrated in Figure 2.

Exchangeable calcium in the soil increased as the particle size of the limestones decreased and as pH increased. Where calcitic limestone was added, larger amounts of exchangeable calcium were found than where similar sized dolomite was applied. This was due to the higher content of calcium and greater degree of solubility of the calcitic stone. Exchangeable calcium in all calcitic limestone treatments, with the exception of the 8-20 mesh, exceeded that found in soils where dolomite had been added. Soil treated with either the calcium hydroxide or carbonate had approximately the same amount of exchangeable calcium as soil where the finer particles of calcitic limestone were applied.

Exchangeable magnesium, as determined by the versenate method, was higher in the limed soil than in the unlimed soil. In the titration of unlimed samples no endpoint was observed in soil extracts from pots where no lime, 8-20 mesh calcitic and 8-20 and 20-40 mesh dolomitic limestone had been added. It was assumed that this was due to either a very small amount of magnesium in the soil or interfering ions existing at low pHs. Calcitic limestone smaller than twenty mesh, and calcium carbonate and hydroxide increased magnesium availability without relation to mesh size or final pH of the soil. Dolomitic limestone increased exchangeable magnesium as particle size decreased.

None of the limestone had any significant effect on the exchangeable potassium, a finding similar to that of Pretty (33), though at variance with that of Dean (18) and Opitz and associates (30), who found addition of lime increased availability as measured by chemical tests.

Five tons of lime per acre. The addition of five tons of lime per acre to an acid sandy loam soil resulted in pH values somewhat similar to those obtained by the two ton treatments. Again the calcium hydroxide and carbonate and calcitic limestone finer than two hundred mesh caused a fast initial reaction followed by, in the case of the hydroxide, a gradual decrease in pH. Calcium carbonate and the less than two hundred mesh calcitic stone maintained approximately the same soil pH after their initial high values. The reaction rate of the other size particles, as shown in Figure 4 and Table IV, was somewhat slower with only those soils treated with the 100-200 mesh

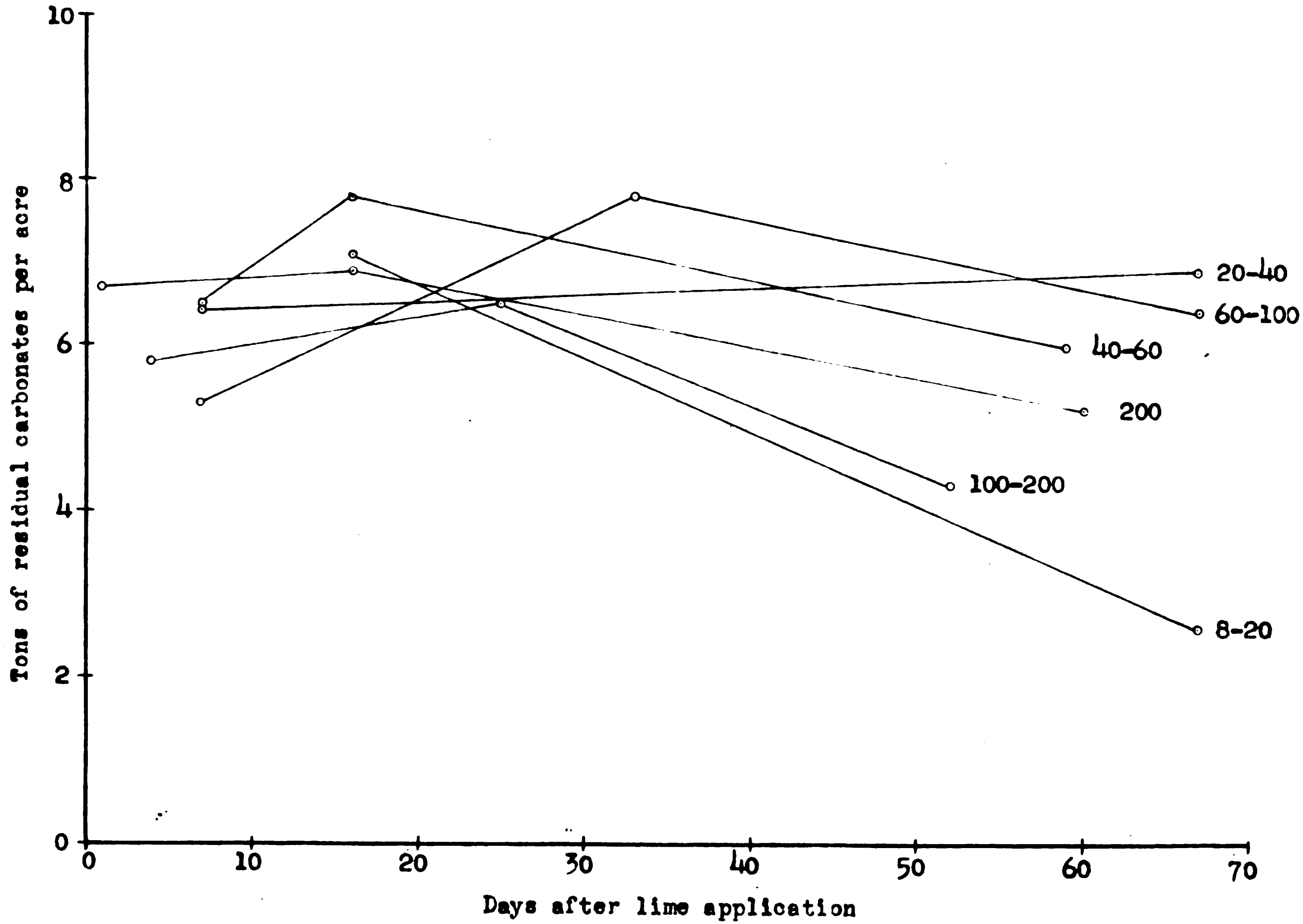

Figure 9. The effect of particle size (mesh) on amount of residual carbonates where dolomitic limestone was applied to a sandy loam soil at a rate equivalent to eight tons of calcium carbonate per acre.

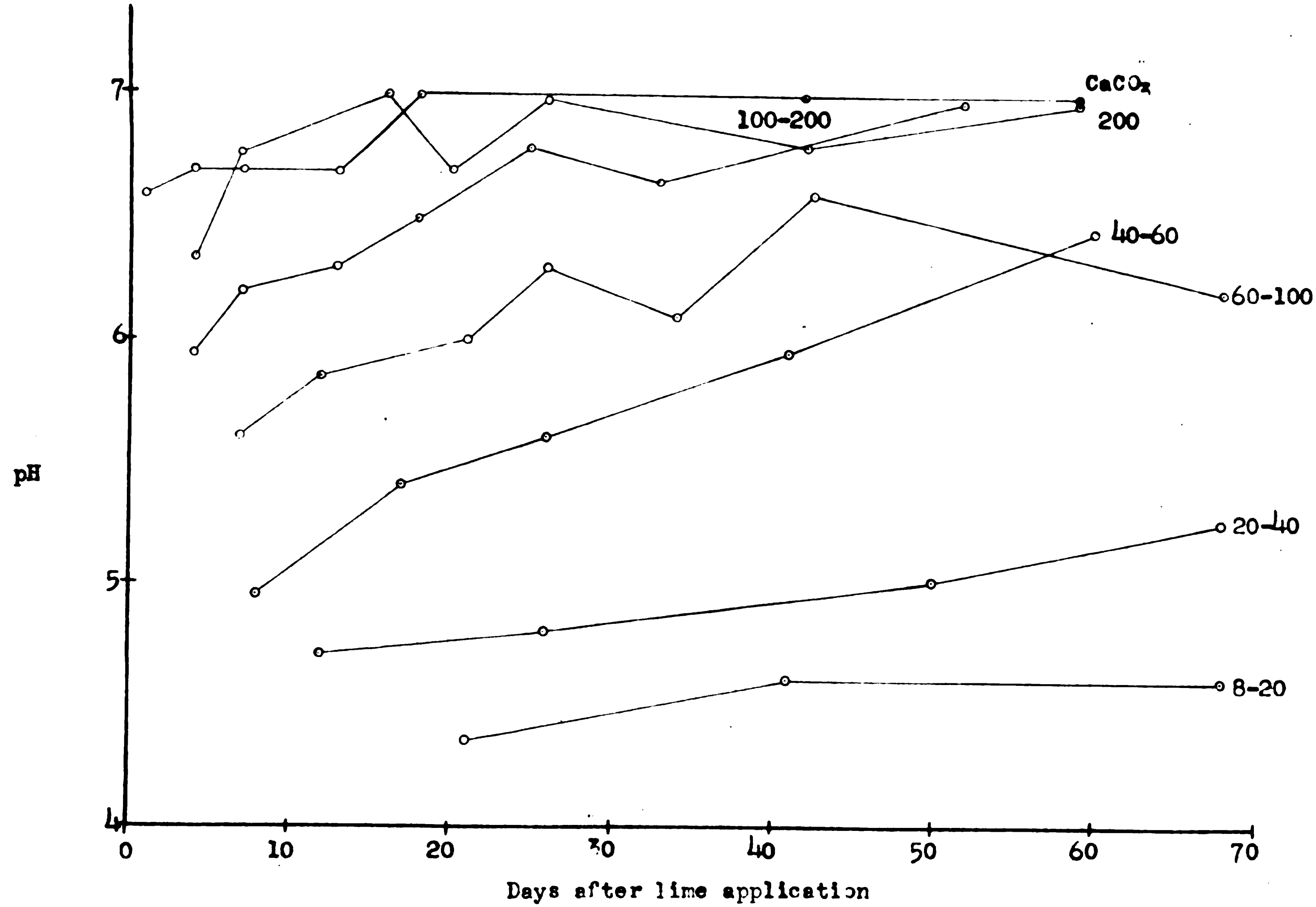

Figure 4. The effect of particle size (mesh) on change in the soil reaction where calcitic limestone and precipitated calcium carbonate were applied to a sandy loam soil at a rate equivalent to five tons of calcium carbonate per acre.

reaction between lime and soil, except that the 8-20 mesh material underwent almost no reaction.

Dolomitic limestone, mixed with soil, shown in Table V and Figure 10, caused an increase in pH for three of the four finest particle sizes over that obtained with the five ton treatments. No increase in pH was evident when the liming rate was increased from five to eight tons of dolomite in the 20-40 and 8-20 mesh treatments. Data shown in Figure 9 show little relation between soil reaction and residual carbonates. Calcium hydroxide and carbonate both increased pH over that developed by the five ton applications.

In most cases there was an increase in exchangeable calcium in soil receiving the eight-ton treatments resulting in higher values than those for the five-ton rate. Greater increases were obtained when calcium was determined by the flame photometer than by the versenate method. As previously mentioned, this is at least partly due to the solubility of carbonates in 1N neutral ammonium acetate.

No endpoints in the magnesium determinations by the versenate method were found on soils treated with the two finest particle sizes of calcitic limestone, calcium hydroxide and carbonate and 8-20 mesh dolomitic limestone.

Exchangeable potassium was not affected by any of the treatments.

Organic Soil

Three tons of lime per acre. An interesting point in using this soil was that for the addition of the various particle sizes of calcitic

Table VI. **The effect of kind of lime and particle size on pH, residual carbonates, exchangeable calcium by two methods, magnesium and potassium when applied to Rifle peat.**[1]

Mesh size	Days of incubation	Final pH	Pounds of exchangeable cations per acre[2]			
			Calcium		Magnesium	Potassium
			Photometer	Versenate		
			Calcitic limestone			
200	28	5.1	3,020	2,916	420	70
100-200	54	5.0	2,660	2,730	374	60
60-100	59	5.0	2,700	2,456	818	70
40-60	59	5.0	2,640	2,768	330	70
20-40	68	4.8	1,980	2,124	306	68
8-20	68	4.4	1,390	1,226	482	64
			Dolomitic limestone			
200	36	5.1	1,430	1,7[illegible]	1,020	62
100-200	45	5.0	1,480	1,912	1,030	62
60-100	58	5.1	1,490	1,924	958	64
40-60	67	5.1	1,240	1,364	642	48
20-40	67	4.7	1,410	1,620	740	68
8-20	58	4.4	1,000	1,066	446	64
			Calcium hydroxide			
200	14	5.4	3,580	3,466	520	68
			Calcium carbonate			
200	14	5.4	2,740	2,804	310	60

[1] **Original soil pH 4.2. Lime added to soil equivalent to three tons of calcium carbonate per acre.**

[2] Soil extracted with 1N neutral ammonium acetate for three hours.

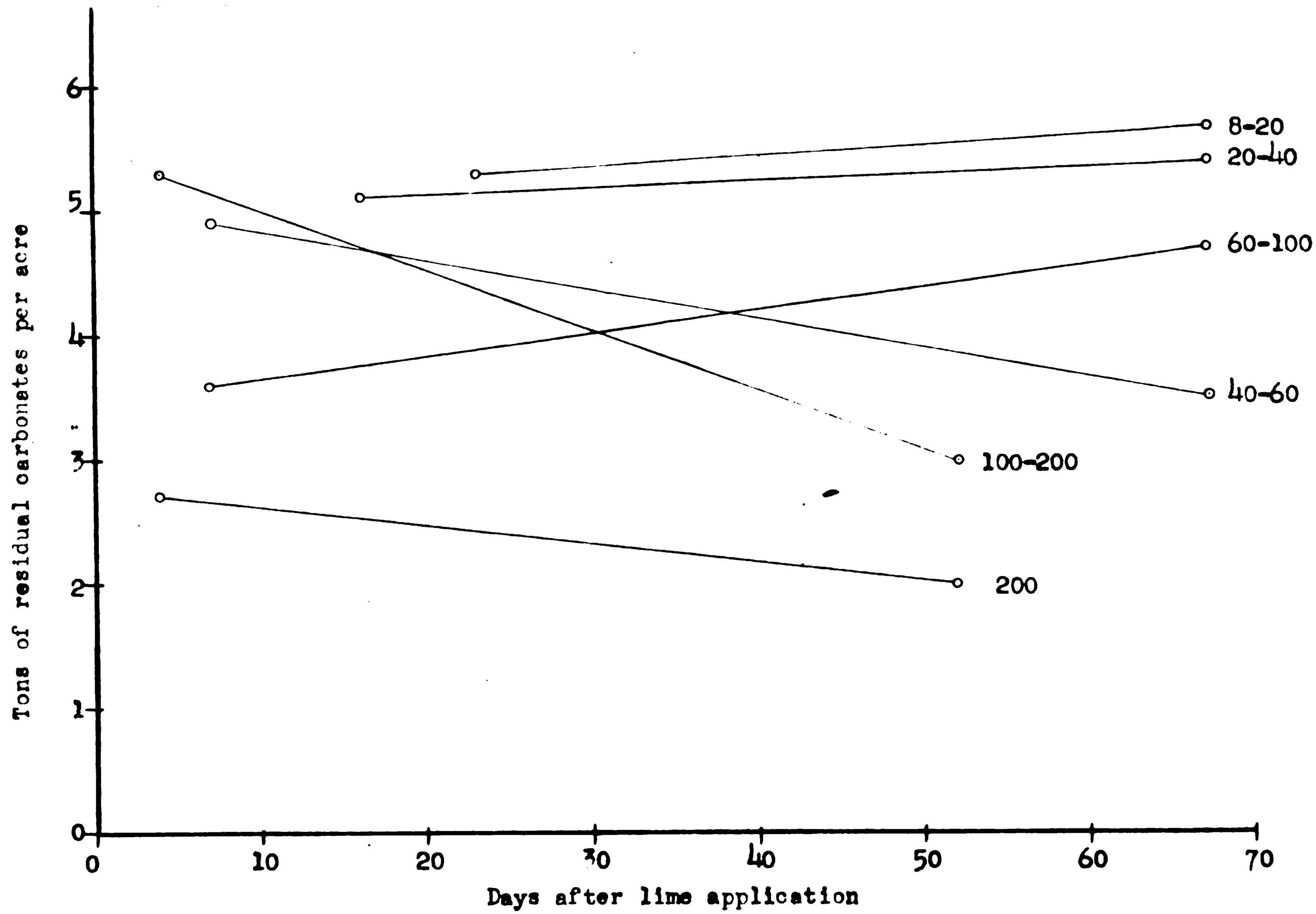

Figure 5. The effect of particle size (mesh) on amount of residual carbonates where dolomitic limestone was applied to a sandy loam soil at a rate equivalent to five tons of calcium carbonate per acre.

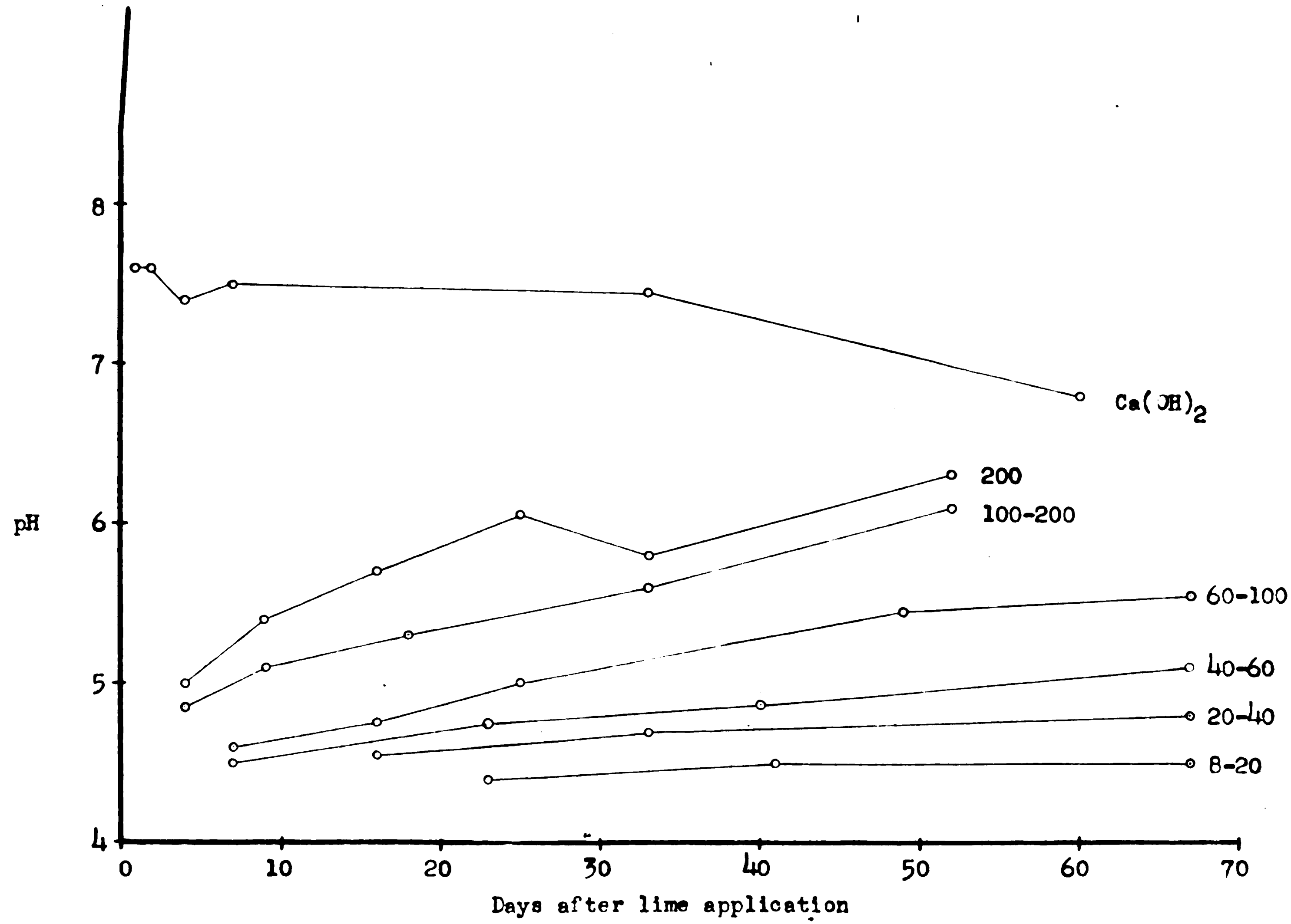

Figure 6. The effect of particle size (mesh) on change in the soil reaction where dolomitic limestone and calcium hydroxide were applied to a sandy loam soil at a rate equivalent to five tons of calcium carbonate per acre.

treated soils contained approximately the same amount of exchangeable calcium as did those soils which received the finer sized calcitic limestone.

Unlike the two-ton applications, the fine grades of calcitic limestone and calcium carbonate and hydroxide when applied at the five-ton rate had a repressing effect on the amount of exchangeable soil magnesium. Cooper (14) has suggested that when calcitic limestone is added to the soil it aggravates magnesium deficiency by retarding the hydrolysis of the magnesium complexes, and when plants are grown calcium ions are absorbed before magnesium. Another possible explanation is that the large amount of calcium or other interfering ions may have masked the endpoint of the magnesium in the versenate titration. Exchangeable magnesium increased with decreasing particle size in soils where dolomitic limestone was applied.

None of the series of treatments gave any marked differences in the amount of exchangeable soil potassium.

Eight tons of lime per acre. An application of eight tons per acre of calcitic limestone finer than 200 or of 100-200 mesh increased the pH only slightly higher than did the same size fractions when used at five ton rates during the same incubation period. These data are shown in Table V and Figures 4 and 8. Where 60-100, 40-60 and 20-40 mesh stones were used there was a significant increase in pH over that obtained from the five ton treatment. Residual carbonates per acre, as presented in Figure 7, do not present a clear picture of the

Table VII. The effect of kind of lime and particle size on pH, residual carbonates, exchangeable calcium by two methods, magnesium and potassium, when applied to Rifle peat.[1]

Mesh size	Days of incubation	Tons of residual carbonates per acre[2]	Final pH	Pounds of exchangeable cations per acre[3]: Calcium, Photometer	Calcium, Versenate	Magnesium	Potassium
			Calcitic limestone				
200	28	0.0	5.7	4,800	4,730	528	62
100-200	54	0.0	5.6	4,080	4,276	388	60
60-100	58	0.0	5.8	4,600	4,714	420	66
60-40	68	0.8	5.6	4,080	4,364	388	64
20-40	68	2.8	5.2	3,400	4,068	385	62
8-20	68	5.6	4.6	1,560	1,788	316	60
			Dolomitic limestone				
200	36	0.0	5.8	1,910	2,892	1,686	64
100-200	45	0.0	5.9	1,990	2,912	1,728	64
60-100	57	1.6	5.9	1,910	2,562	1,384	64
40-60	67	2.1	5.4	1,910	2,358	1,422	68
20-40	67	3.9	5.0	1,700	2,082	1,010	64
8-20	67	9.5	4.5	1,180	1,302	600	70
			Calcium hydroxide				
200	14	-	6.2	5,320	5,676	510	66
			Calcium carbonate				
200	14	0.0	5.9	4,530	4,644	326	60

[1] Original soil pH 4.2. Lime added to soil equivalent to six tons of calcium carbonate per acre.

[2] Calcium carbonate basis.

[3] Soil extracted with 1N neutral ammonium acetate for three hours.

and dolomitic limestone at the three-ton rate all particles smaller than 40 mesh resulted in approximately the same pH at the end of the incubation period, as shown in Table VI and Figures 11 and 12. However, the curves for change in soil reaction with time were different for these liming materials. Soils treated with 100-200 or finer than 200 mesh limestone reached a pH of 5.0 or above in ten to twenty days. They either remained at about that value or decreased to a lower pH. Where the 60-100 and 40-60 mesh stones were used soil pH gradually increased; until at the end of the incubation period these soils were nearly the same pH as soils which received the finer materials. A reduction in pH after the first few weeks in soils treated with the finest fractions may be due to the decomposition of organic matter and the accompanying formation of nitric acid, or possibly the lack of reaction between lime and soil. The 8-20 mesh stone was ineffective as a neutralizing agent.

Calcium carbonate and hydroxide resulted in a higher final soil pH than any of the other soil amendments, partially due to the short incubation period, which did not allow time for the stimulation of nitrification.

There was only a small variation in exchangeable calcium in soil treated with calcitic limestone finer than 40 mesh. The 20-40 and 8-20 mesh particles were not as effective as the finer sizes in their ability to increase the amount of exchangeable calcium in the soil. The differences which were obtained in the two methods for determination of calcium on soils treated with calcium lime were small since the same extracting solution, 1N neutral ammonium acetate, was used in both cases.

Upon incubation approximately the same amount of exchangeable calcium was found in soils treated with any particle size of the dolomitic stone, except the coarsest material. For an unknown reason, the exchangeable calcium contents as determined by the versenate method were consistently higher than those by the photometer on soils treated with dolomitic limestone.

Calcitic limestone, calcium hydroxide and carbonate had little or exchangeable calcium when determined by the flame photometer; but again, as in the case of the three-ton application, values for calcium as determined by the versenate method were greater. The latter method also resulted in greater variation in the calcium than the former procedure. Calcium hydroxide treated soils contained the greatest amount of exchangeable calcium and were the highest in pH of any of the six ton lime treatments. This was partly due to the short incubation period.

There seemed to be no particular effect of the calcitic limestone on the exchangeable magnesium in the soil. An increase in magnesium accompanied decreasing particle size where dolomitic limestone was applied. Generally, the six ton applications of dolomite increased exchangeable magnesium by about one-third over that obtained with three-ton treatments.

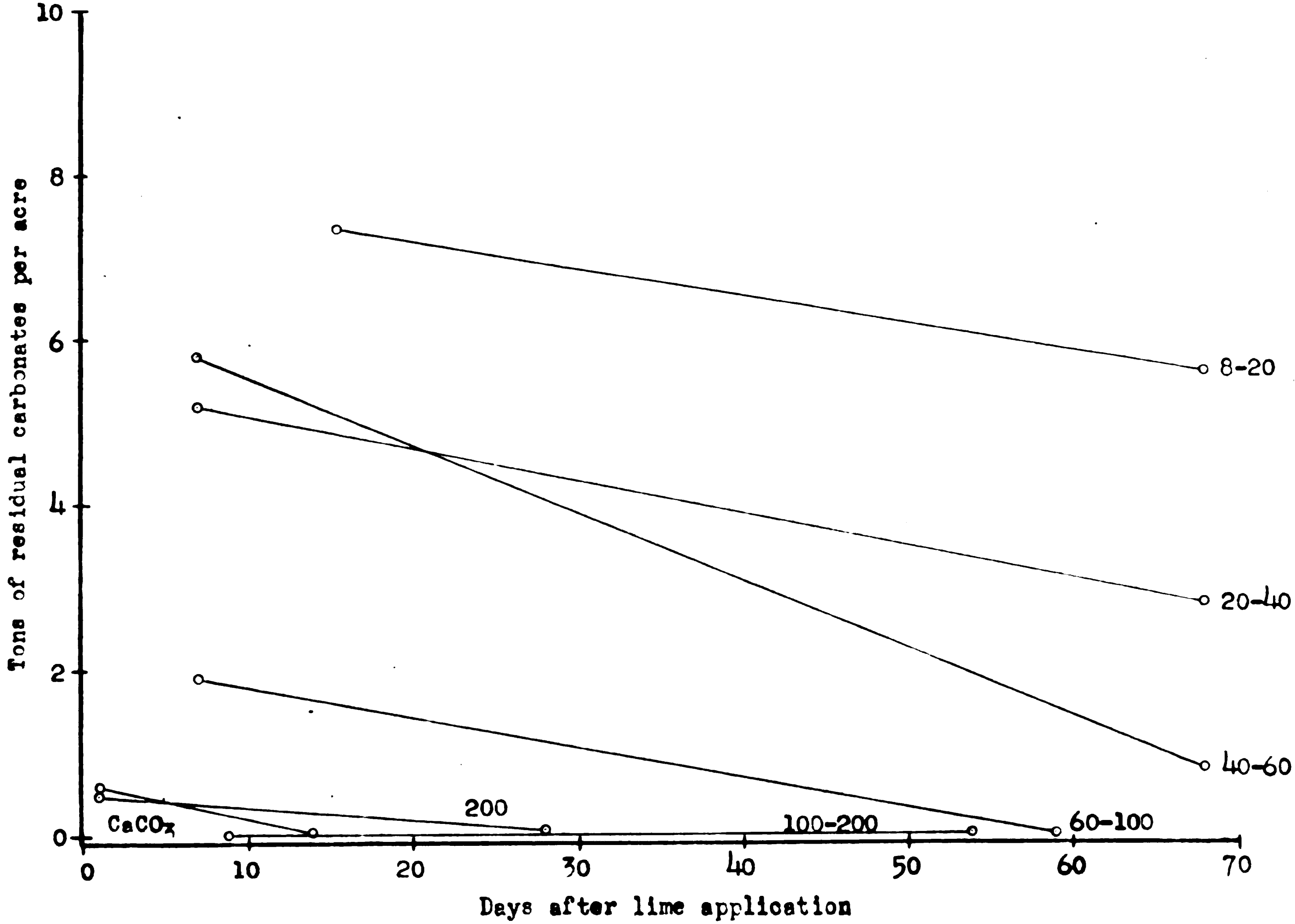

Figure 13. The effect of particle size (mesh) on amount of residual carbonates where calcitic limestone and precipitated calcium carbonate were applied to an organic soil at a rate equivalent to six tons of calcium carbonate per acre.

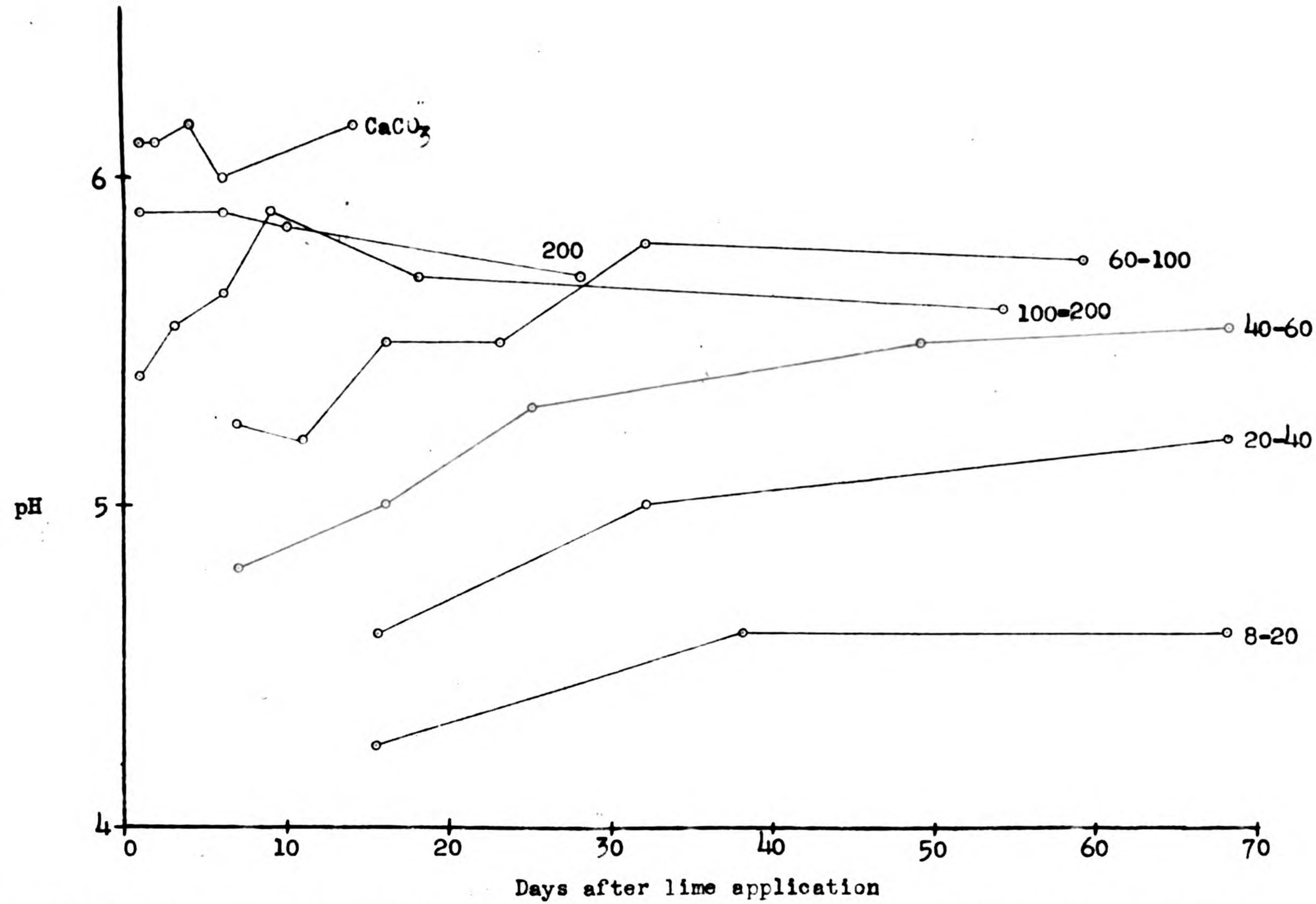

Figure 14. The effect of particle size (mesh) on change in the soil reaction where calcitic limestone and precipitated calcium carbonate were applied to an organic soil at a rate equivalent to six tons of calcium carbonate per acre

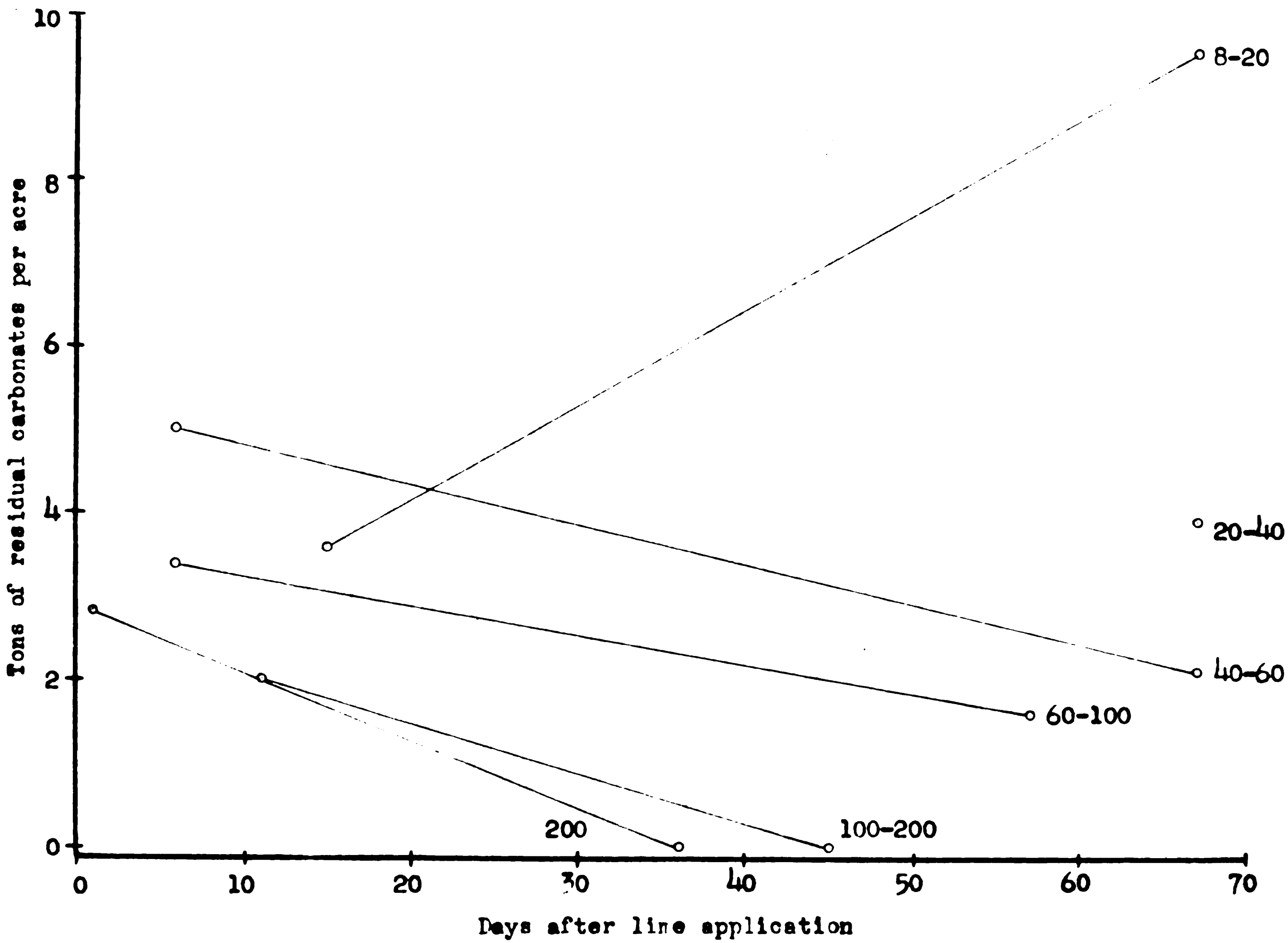

Figure 15. The effect of particle size (mesh) on amount of residual carbonates where dolomitic limestone was applied to an organic soil at a rate equivalent to six tons of calcium carbonate per acre.

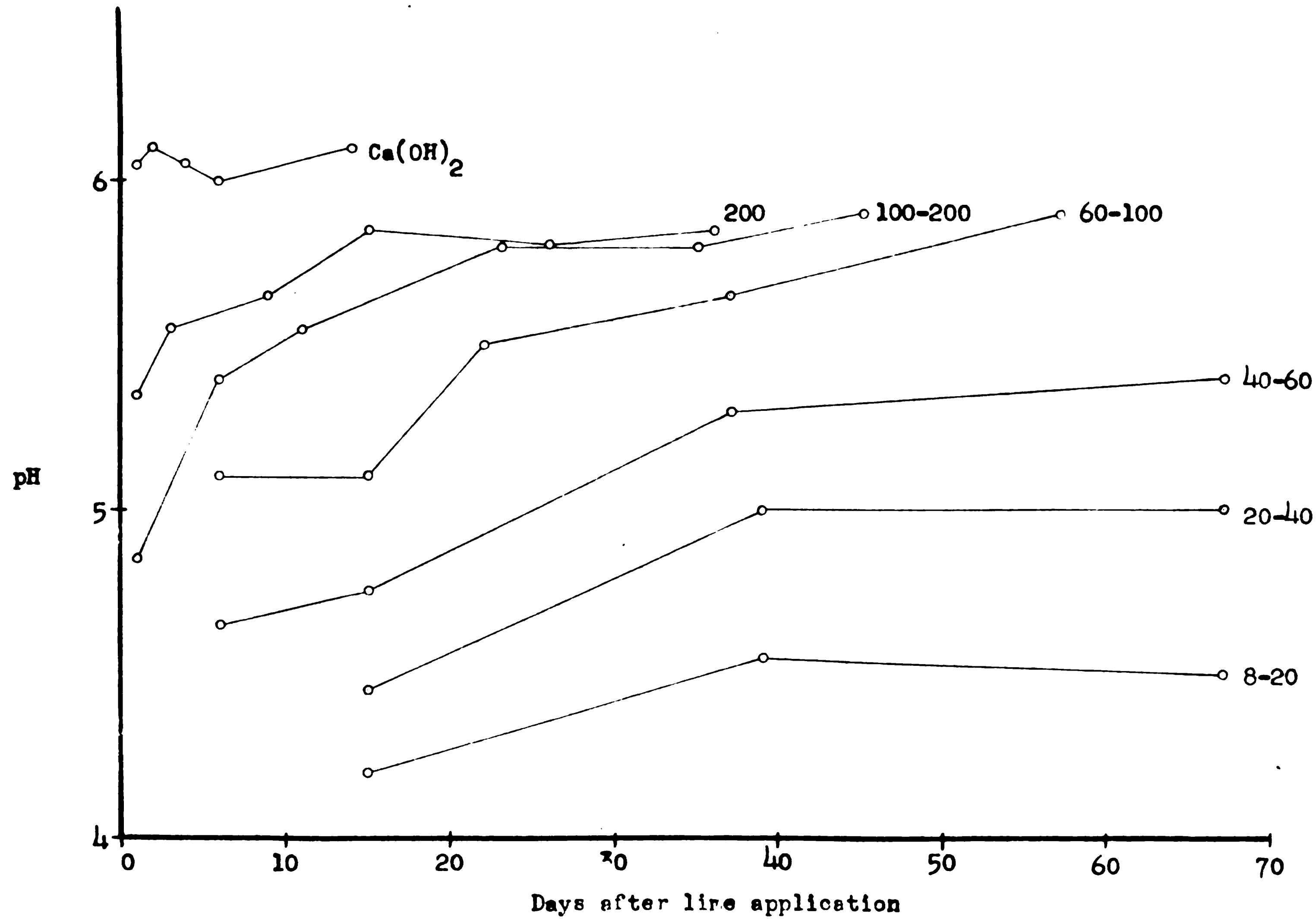

Figure 16. The effect of particle size (mesh) on change in soil reaction where dolomitic limestone and calcium hydroxide were applied to an organic soil at a rate equivalent to six tons of calcium carbonate per acre.

Twelve tons of lime per acre. Only calcium carbonate and hydroxide brought the pH of the soil above the neutral point as shown in Table VIII and Figures 18 and 20. It is difficult to say if these pH values would have fallen had the incubation period been lengthened to that of the other treatments since there was a trace of free carbonates present in the soil treated with the precipitated calcium carbonate. One of the treatments with calcitic limestone, the 100-200 mesh, showed a slight decline in pH after free carbonates were either low or had disappeared from the soil. The three finest mesh sizes of calcitic limestone were approximately equally effective in obtaining a high pH of 6.8. The 40-60 mesh size was nearly as effective as the finer grades in reducing acidity, though the increase in pH was more gradual. Twelve tons of the 8-20 mesh calcitic limestone increased the pH to 4.9, only slightly higher than that resulting from the application of three tons of 20-40 mesh particles.

Dolomitic limestone was not as efficient as the calcitic limestone in correcting soil acidity. Rate of reaction was somewhat slower than for calcitic limestone of the same particle size. Peat treated with the three finest sized particles reached approximately the same pH, 6.5, by the end of the incubation period, though, as in other instances, the larger the particle the slower was the change in pH. Coarse 8-20 mesh dolomite was ineffective in raising pH and the 20-40 and 40-60 mesh particles were intermediate in their action.

Residual carbonate analyses, as shown in Figures 17 and 19, reveal an almost immediate reduction in free carbonates and a later gradual reduction in the amount of residue where the four finest size dolomite and calcitic limestone materials were used. Little change took place in the residues of the 8-20 mesh applications, though there were fluctuations in sample contents above the twelve tons of lime applied.

Exchangeable soil calcium increased with the fineness of the material added to the soil, with the finer than 200 mesh calcitic limestone and calcium hydroxide the highest, and the coarsest dolomitic limestone the lowest.

The total base saturation of the soil and to which twelve tons of 60-100 mesh calcitic limestone was applied was found to be 64 percent when considering the sum of exchangeable calcium, magnesium and potassium contents. This value was obtained using the quantity of calcium as determined by the flame photometer. This figure may be somewhat in error due to the solubility of calcitic limestone in 1N neutral ammonium acetate. A dolomitic limestone, the less than 200 mesh, produced a somewhat similar pH with a base saturation of only 55 percent when added to soil at the same rate.

No pronounced effect on exchangeable potassium was found as a result of the lime treatments.

Table VIII. The effect of kind of lime and particle size on pH, residual carbonates, exchangeable calcium by two methods, magnesium and potassium when applied to Rifle peat.[1]

Mesh size	Days of incubation	Tons of residual carbonates per acre[2]	Final pH	Pounds of exchangeable cations per acre[3]			
				Calcium		Magnesium	Potassium
				Photometer	Versenate		
			Calcitic limestone				
200	29	1.9	6.8	9,940	8,428	558	68
100-200	54	0.0	6.6	6,720	2,180	1,076	60
60-100	59	2.3	6.8	7,960	6,731	869	74
40-60	59	3.6	6.5	7,480	7,292	438	68
20-40	68	9.4	5.7	4,080	4,988	402	64
8-20	68	14.9	4.8	2,420	2,456	384	66
			Dolomitic limestone				
200	36	3.0	6.6	3,130	3,504	2,324	60
100-200	54	2.6	6.6	2,700	2,904	1,908	50
60-100	58	4.2	6.5	1,680	1,990	968	66
40-60	58	4.9	6.1	2.780	3,292	2,046	72
20-40	67	14.2	5.6	1,890	2,400	1,300	64
8-20	58	19.0	4.6	1,240	1,388	644	62
			Calcium hydroxide				
200	14	-	7.5	9,600	9,676	770	62
			Calcium carbonate				
200	29	Trace	7.2	6,240	6,338	274	54

1 Original soil pH 4.2. Lime added to soil equivalent the twelve tons of calcium carbonate per acre.

2 Calcium carbonate basis.

3 Soil extracted with 1N neutral ammonium acetate for three hours.

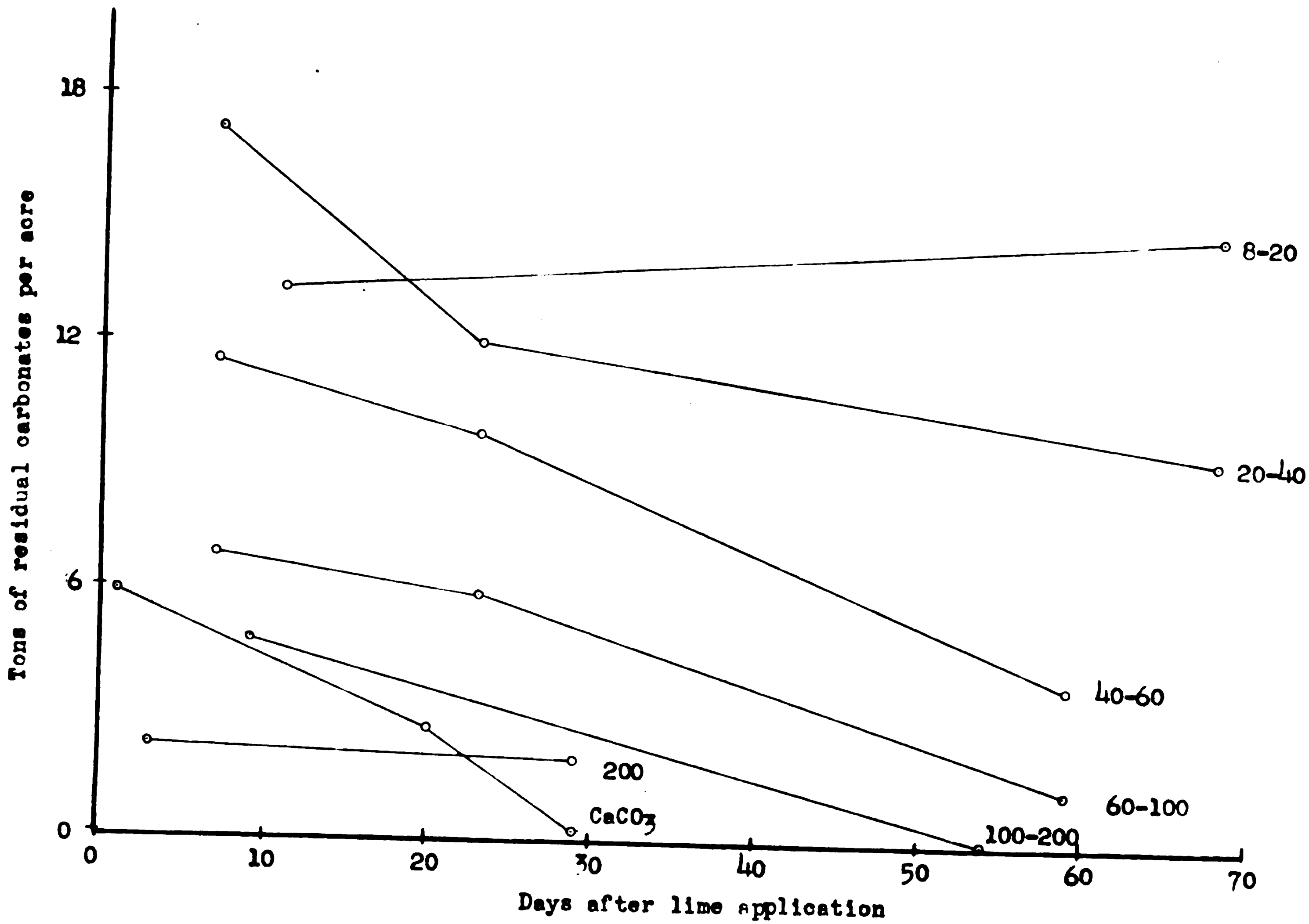

Figure 17. The effect of particle size (mesh) on amount of residual carbonates where calcitic limestone and precipitated calcium carbonate were applied to an organic soil at a rate equivalent to twelve tons of calcium carbonate per acre.

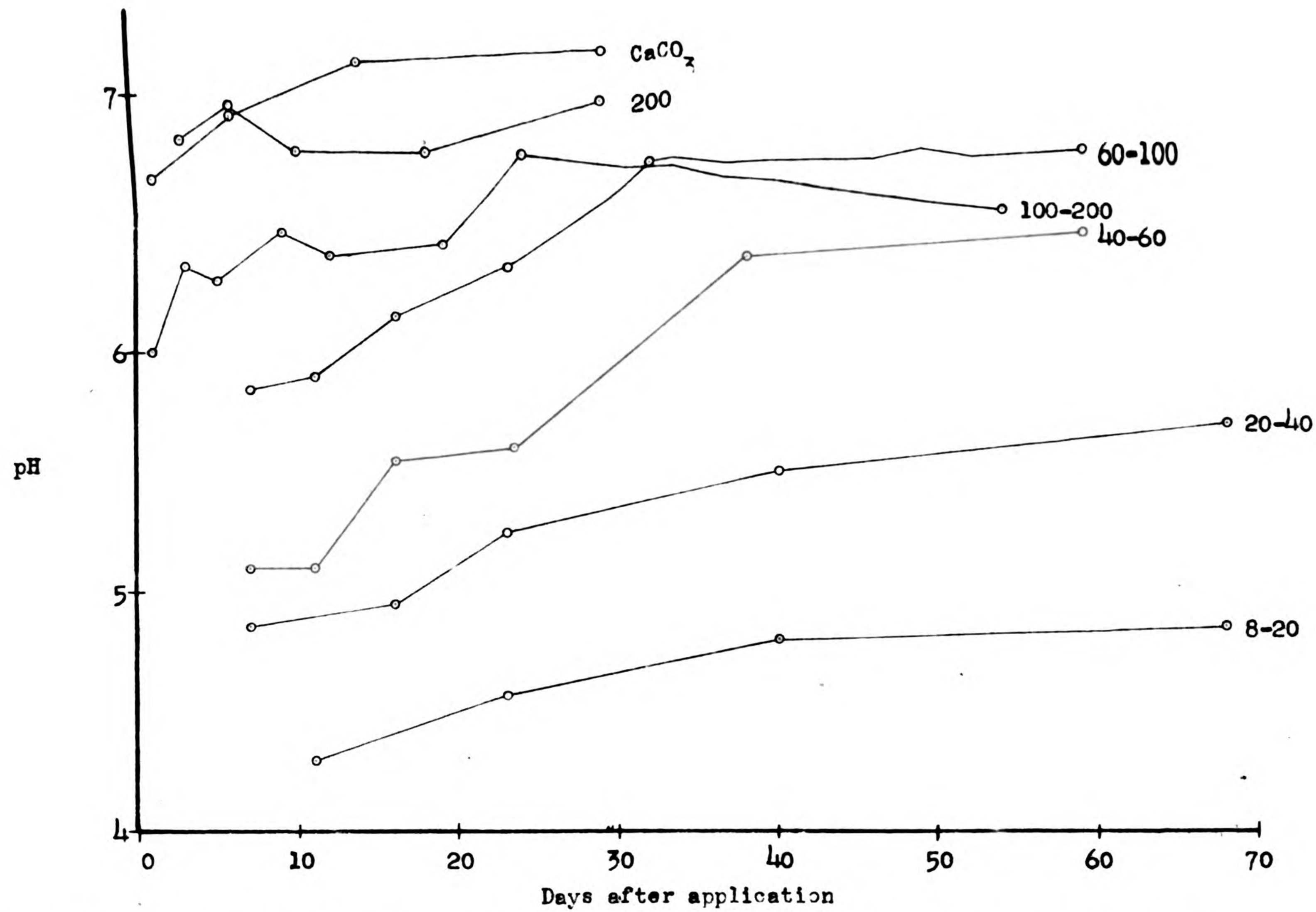

Figure 18. The effect of particle size (mesh) on change in the soil reaction where calcitic limestone and precipitated calcium carbonate were applied to an organic soil at a rate equivalent to twelve tons of calcium carbonate per acre.

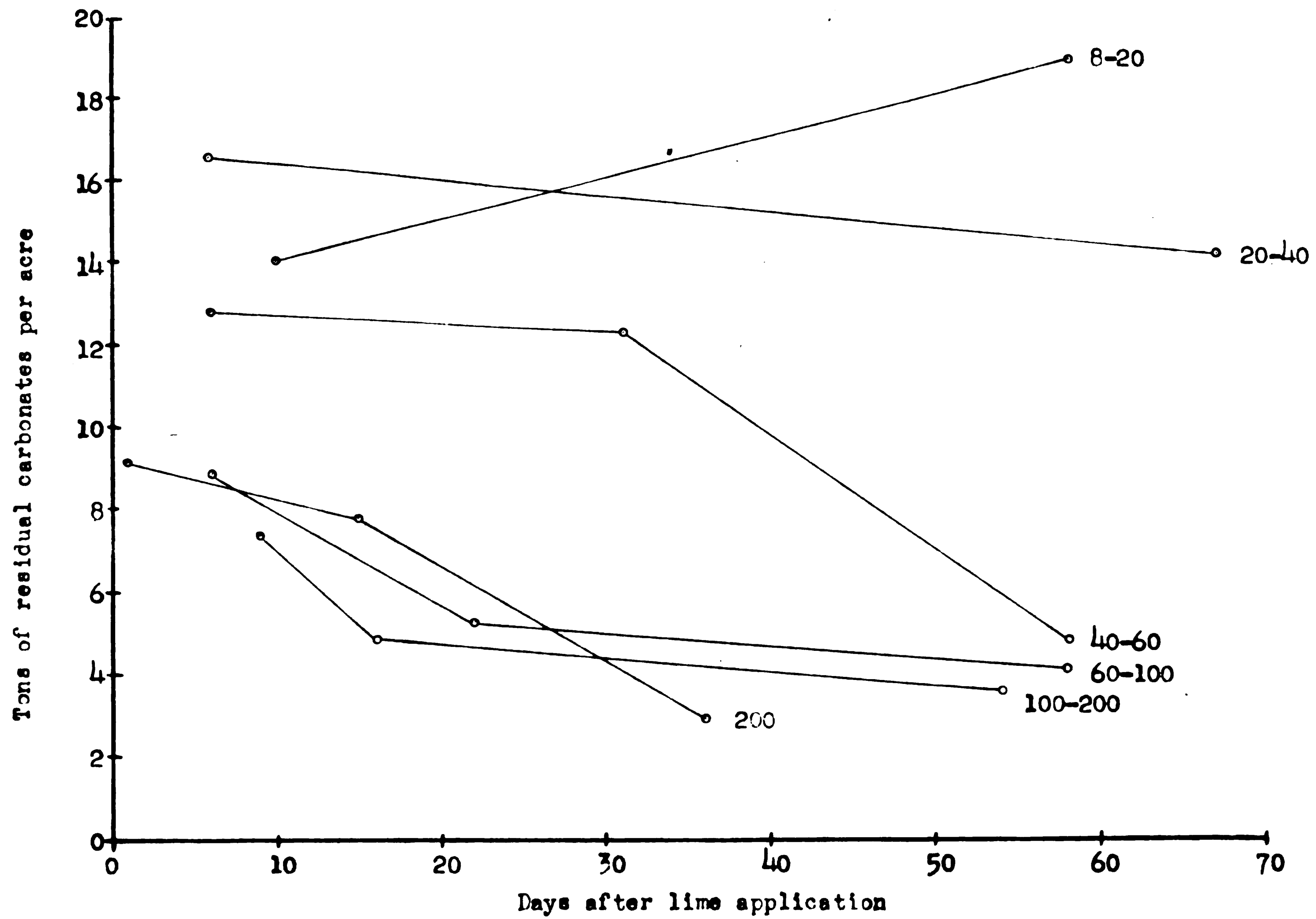

Figure 19. The effect of particle size (mesh) on change in the amount of residual carbonates where dolomitic limestone was applied to an organic soil at a rate equivalent to twelve tons of calcium carbonate per acre.

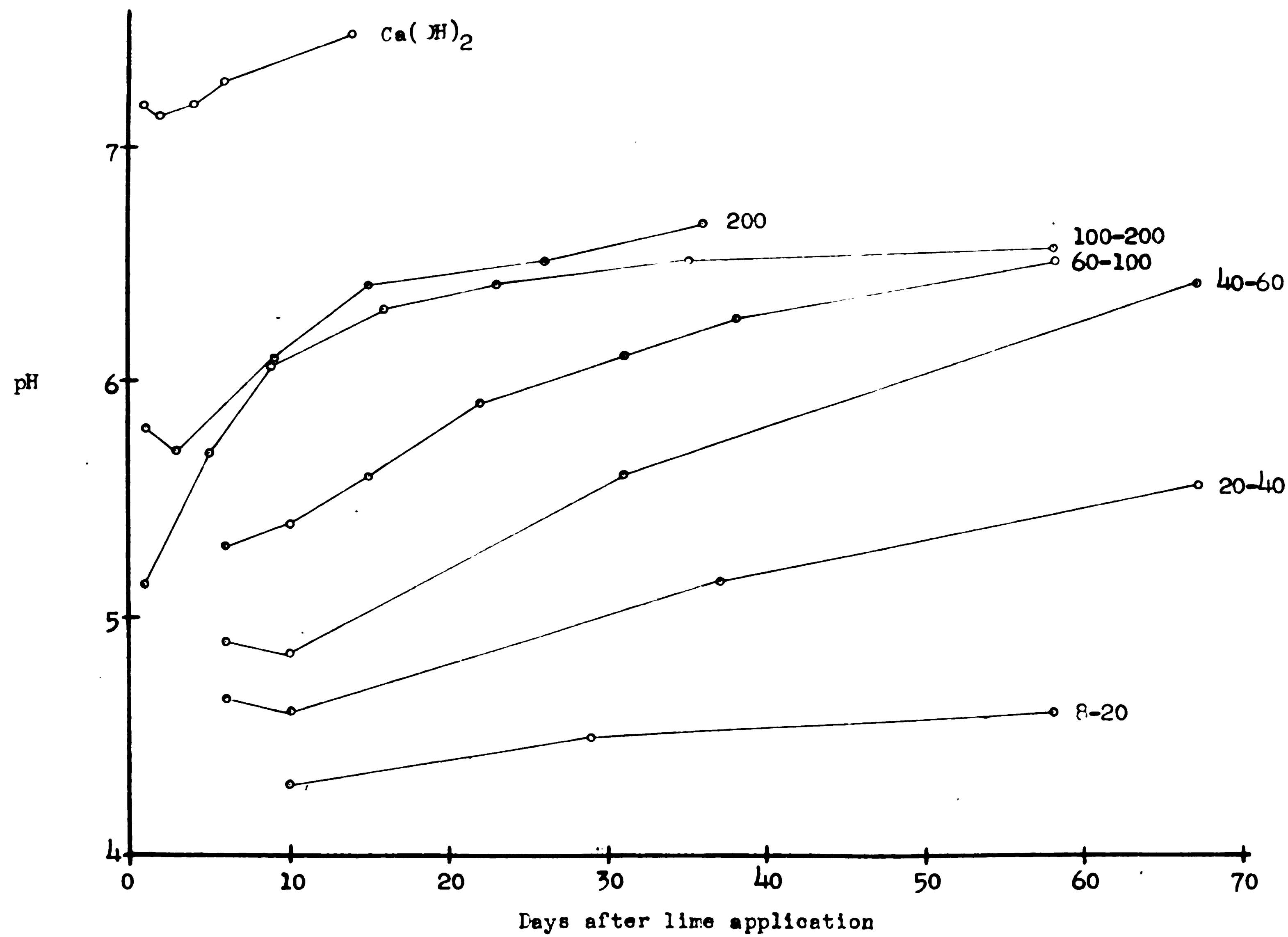

Figure 20. The effect of particle size (mesh) on change in the soil reaction where dolomitic limestone and calcium hydroxide were applied to an organic soil at a rate equivalent to twelve tons of calcium carbonate per acre.

Plants

Mineral soil. Two weeks after planting the first samples of corn were harvested for analysis of fertilizer phosphorus, applied at the rate of 100 pounds of P_2O_5 per acre as concentrated superphosphate. At this sampling time severe phosphorus deficiencies were noted on several plants grown on soils with pHs from 4.7 to 7.3. Data in Table IX shows there was little uptake of applied phosphorus the first two weeks. No relationship between lime and uptake of P^{32} exists on these soils.

At the final harvest, four weeks after planting, a general increase in the P^{32} content was noted, but fertilizer phosphorous absorption did not appear to be related to kind or amount of liming material. At this time nearly all the plants were showing severe phosphorus deficiencies. The poor physical condition of the soil may have been one of the factors responsible for the unavailability of P^{32}.

Organic soil. The analysis of the samples, shown in Table X, indicates the lowest uptake of fertilizer phosphorus when soils were treated with twelve tons of the finer mesh limestones and calcium carbonate and hydroxide. No clear relationship exists between particle size of liming material and fertilizer phosphorus absorption, though a general reduction in applied phosphorus is evident as rate of lime was increased. These data are similar to those of Lawton and Davis (23). It was not known whether the low uptake of phosphorus fertilizer on soils where the larger amounts of lime were added was due to the formation of insoluble calcium and magnesium phosphates, or to the decomposition of organic matter and a subsequent release of organic phosphates, thus diluting the fertilizer phosphorus. No phosphorus deficiency symptoms on plants were evident with any of the lime treatments. Average value of fertilizer phosphorus uptake in the two-week sample for the calcitic limestone was 17.4, and for the dolomitic limestone 21.5 milligrams per gram of oven-dry plant material. This difference may be due to either decomposition of organic matter of fixation of applied phosphorus.

Four weeks after planting, the samples showed a reduction in the uptake of fertilizer phosphorus with the corn grown on soils treated with calcitic limestone having an uptake of 7.6 and that grown on the dolomite treated soils 8.0 milligrams per gram of plant material. It is interesting to note the small difference between the uptake at this time as compared with the difference at the end of the two-week period. This lack of difference may be attributed to either greater decomposition of organic matter or an increase in the fixation of phosphorus in the dolomite treated soil, which would affect plant availability.

Table IX. The effect of kind, particle size, and rate of application of lime on the uptake of P_2O_5, with phosphorus as P^{32}, by corn at two and four week intervals after planting on a sandy loam soil.

Mesh size	Rate (Tons per acre)	P_2O_5 content * Calcitic limestone Two weeks	Calcitic limestone Four weeks	Dolomitic limestone Two weeks	Dolomitic limestone Four weeks
200	8	0.5	1.3	1.1	1.4
100-200	8	1.4	1.7	0.8	1.5
60-100	8	0.6	1.2	1.0	1.7
40-60	8	0.7	1.5	1.0	1.7
20-40	8	0.6	1.5	1.1	1.6
8-20	8	1.3	1.8	1.7	2.8
200	5	0.9	1.3	0.9	1.8
100-200	5	1.4	1.7	2.3	2.0
60-100	5	0.9	1.8	0.9	1.7
40-60	5	0.7	1.2	1.4	1.8
20-40	5	0.5	1.5	2.2	2.0
8-20	5	0.6	1.7	0.8	1.7
200	2	0.9	1.9	1.0	1.8
100-200	2	1.4	2.2	1.3	2.1
60-100	2	0.7	1.3	0.9	1.5
40-60	2	0.9	1.3	1.4	2.1
20-40	2	1.6	2.1	1.3	1.9
8-20	2	0.7	2.0	0.9	1.9

Precipitated calcium carbonate

Rate (Tons per acre)	Two weeks	Four weeks
8	0.6	1.2
5	0.9	1.5
2	0.8	1.9

Calcium hydroxide

Rate (Tons per acre)	Two weeks	Four weeks
8	0.3	1.0
5	0.8	1.5
2	0.7	1.2

Check

Two weeks	Four weeks
1.2	2.1

* Milligrams of fertilizer P_2O_5 per gram of oven dry plant material.

Table X. The effect of kind, particle size, and rate of application of lime on the uptake of P_2O_5, with phosphorus as P^{32}, by corn at two and four week intervals after planting on Rifle peat.

Mesh size	Rate (Tons per acre)	P_2O_5 content * Calcitic limestone Two weeks	Calcitic limestone Four weeks	Dolomitic limestone Two weeks	Dolomitic limestone Four weeks
200	12	5.3	3.6	7.0	4.0
100-200	12	7.0	3.7	8.5	4.0
60-100	12	7.6	4.1	23.5	6.5
40-60	12	8.6	4.7	9.6	4.2
20-40	12	14.3	5.3	16.9	7.4
8-20	12	17.5	6.7	25.2	7.3
200	6	17.6	7.8	25.8	11.4
100-200	6	15.6	6.7	17.2	7.5
60-100	6	16.2	8.1	16.8	7.6
40-60	6	21.6	7.7	19.4	7.3
20-40	6	13.5	5.9	34.1	9.4
8-20	6	25.3	10.0	23.9	9.7
200	3	38.7	17.7	26.6	9.0
100-200	3	19.7	8.0	20.4	6.5
60-100	3	30.2	10.5	25.2	8.0
40-60	3	15.2	7.7	36.3	12.2
20-40	3	22.9	10.3	29.4	12.1
8-20	3	16.4	8.0	20.3	8.9

Rate	Precipitated calcium carbonate Two weeks	Four weeks
12	6.7	5.6
6	21.1	7.7
3	24.2	9.1

Rate	Calcium hydroxide Two weeks	Four weeks
12	4.2	4.5
6	16.2	7.2
3	10.4	9.4

Rate	Check Two weeks	Four weeks
0	18.1	10.0

* Milligrams of fertilizer P_2O_5 per gram of oven dry plant material.

SUMMARY

The effects of amount, kind, and particle size of lime on the pH, amount of residual carbonates, exchangeable calcium, magnesium and potassium, and the uptake of phosphorus fertilizer by corn plants grown on an organic and a sandy loam soil, were studied over a two month period.

As the application rate of calcitic and dolomitic limestone increased on the sandy loam soil, the final pH also increased in most cases. An exception to this was when treatments of five and eight tons of less than 200 and 100-200 mesh dolomitic and calcitic limestones were used. In these instances the five ton applications were found to be as effective as the eight ton applications. For each application rate, calcitic limestone of less than 200, 100-200 and 60-100 mesh were equally effective in raising the pH over the two month incubation period. Due to greater insolubility and smaller total surface area applied per treatment, dolomitic limestone corrected soil acidity more slowly and less effectively than calcitic limestone and calcium carbonate and hydroxide. Particles greater than twenty mesh in size were ineffective in raising soil pH.

The reaction of the organic soil increased more slowly than that of the mineral soil due to the high buffer capacity of the organic matter. Each additional increment of lime increased the pH of the soil. Dolomitic and calcitic limestones of the three finest particle

sizes were equally effective in changing soil reaction. There was little effect on soil acidity by particles larger than 20 mesh.

Calcitic limestone and precipitated calcium carbonate dissolved more quickly than dolomitic limestone when applied to soil. Considerable variation in the quantity of residual carbonates was found for the various liming materials applied to the mineral soil. Sampling errors are believed to be the main problem involved. With the organic soil, more logical and uniform curves for residual carbonate were obtained. The breakdown of carbonate lime was more rapid in the organic soil than in the mineral soil studied.

Exchangeable calcium increased with rate of application and decrease in particle size where an excess of carbonates were present in the soil. At the same rate of application, soils treated with all sizes of calcitic limestone, except greater than 20 mesh, contained more exchangeable calcium than any of the dolomite treated soils.

Variations in the exchangeable calcium determination by the flame photometer and versenate titration utilizing mineral soil extracts are believed to be due mainly to differences in method of extraction, and extracting solution. However, when the same extracting solution was used on organic soils treated with dolomitic limestone, the versenate method of determination was consistently higher than those of the flame photometer for unknown reasons.

Up to a pH of about 6.9, calcitic limestone, calcium carbonate and hydroxide increased exchangeable magnesium compared with that found in the original mineral soil, but at pH 7.0 and above no exchangeable magnesium was found. Dolomitic limestone increased exchangeable magnesium consistently as particle size decreased. No exchangeable magnesium was found on mineral soils treated with 8-20 mesh dolomite. The calcitic materials had no effect on the amount of exchangeable magnesium found in organic soils.

None of the series of treatments had any effect on the amount of exchangeable potassium in either mineral or organic soil.

Fertilizer phosphorus uptake by plants grown on the mineral soil was not influenced by any of the liming treatments. On organic soil fertilizer phosphorus uptake was inversely related to the rate of lime applied. Greatest reduction occurred when twelve tons of lime were applied. Whether this was caused by the unavailability of the phosphorus fertilizer at the higher pH values or by the greater availability of the organic phosphorus upon liming was not determined.

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