EFFECT OF LIMING UPON PHOSPHORUS AVAILABILITY AND GROWTH OF ALFALFA ON PARSONS SILT LOAM AND GEARY SILT LOAM SOILS

by

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B.S., Kansas State College of Agriculture and Applied Science, 1955

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1956

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INTRODUCTION AND REVIEW OF LITERATURE

Phosphorus has been called the master key to agriculture. Its importance is indicated by the fact that low crop production has been due more often to a lack of phosphorus than to the lack of any other element. Phosphorus is found in every living cell and is considered essential in both plant and animal nutrition. Farmers and agricultural workers have long recognized the important role of soil and fertilizer phosphorus in crop production. The element was discovered in 1669, but had been used in England as a fertilizer in the form of bones as early as 1662.

Experience has shown that many soils in this country are deficient in phosphorus and that the use of phosphatic fertilizers often materially increased crop yields. Comparatively little basic information was known about the phosphorus status of different soils until rather recently. For many years it has been believed that the phosphorus compounds of acid soils are less available than those in well-limed soils. Whitson and Stoddart (8) studied the response of soils to phosphate fertilization and found that the acid soils with which they worked gave a much greater response to phosphatic fertilizer than the non-acid soils. They suggested that in the acid soils the phosphorus was largely present as iron and aluminum phosphates instead of the more available calcium phosphates. This conclusion was supported by their laboratory studies, which indicated that the ratio of iron and aluminum phosphates to calcium phosphates was higher in the acid soils.

High phosphate fixing power of the soil should make for low availability of native phosphorus. This, in turn, should lead to a relatively great need for added phosphorus and a correspondingly high response to phosphatic fertilizers. This same high fixing power should lead to a rapid fixation of added phosphates, and, while the immediate results of such additions might be large, the later response might well be below that from similar additions to a soil with less fixing power.

Salter and Barnes (4) observed in their legume reaction experiment that grain crops show a marked decrease in phosphate response as the pH increases from 5.9 to 7.4. They also observed that hay crops show the same tendency but the most rapid decrease in response occurs between pH 6.8 and 7.4. It was noted that at pH 7.4 the unphosphated yields of corn, oats, and hay were approximately equal to the phosphated yields and were close to the maximum yields obtained in the experiment.

Two possible explanations for the effects mentioned have been advanced. It may be assumed that the availability of the native phosphorus of the soil increases in passing from an acid to an alkaline reaction with a corresponding decrease in the need for fertilizer additions, or it is possible that the availability of the phosphorus supplied as superphosphate decreases as the reaction is made more alkaline.

Recent work of Scarseth and Tidmore (5) indicates that the time of applying either the phosphates or lime in relation to the growth period of the crop may be important. They found with superphosphate and other readily available phosphates a progressive fixation and corresponding decrease in availability with increasing time after application and also a notable depression in the availability of added phosphates when lime was applied at the same time. However, there was a progressive lessening of this effect as the time of the lime application was advanced ahead of the phosphate application.

Truog (6) reported that the liming of distinctly acid soils to near pH 7 will transform rather rapidly considerable amounts of relatively unavailable phosphorus to a readily available form.

Voelcker (7) treated a number of soils with a soluble phosphate and noted a rapid absorption from solution of the phosphate. He concluded that the phosphate was removed from solution by lime and hydrates of iron and aluminum. He was one of the first to suggest absorption of soluble fertilizer phosphates by the hydrated iron and aluminum oxides of soils.

In recent years extensive literature has developed with respect to substances and reactions which are involved when soils absorb and take out of solution soluble phosphates added as fertilizer. It appears that hydrated iron oxide is the principal substance in most acid soils which combines with soluble phosphate in such a manner that the phosphate is made insoluble or only very slightly soluble in weak acids. Hydrated aluminum oxide can act in a similar manner, but the phosphate probably does not become nearly so difficultly available.

In soils phosphorus is associated with calcium to varying degrees depending upon the soil pH and supply of calcium. When the pH of soils drops below 6.5, the tendency for phosphorus to be associated with calcium drops rapidly, as does usually also the availability of the phosphorus for crop use. It appears, therefore, that the liming of acid soils to a pH near the neutral point will promote the availability both of native soil phosphorus and of that applied as a soluble fertilizer.

The objectives of this study were: (1) to ascertain why applications of relatively large amounts of limestone did not cause comparably large changes in pH of the Parsons silt loam at the Thayer Experiment Field; (2) to compare the behavior of Geary silt loam and Parsons silt loam insofar as alfalfa growth and phosphorus availability were concerned; (3) to determine what effect hastening of reaction of limestone with soil had on soil pH and phosphate availability.

METHODS OF STUDY

Soil Material Used

Parsons silt loam soil from the surface six inches was obtained from the Experimental Field near Thayer, Kansas. Geary silt loam soil from the surface six inches was obtained from the Agronomy Farm near Manhattan, Kansas. Both soil materials were quite acid, but the Parsons silt loam contained much less available phosphorus than did the Geary silt loam.

Laboratory Analyses

Laboratory analyses of both the Parsons silt loam soil and the Geary silt loam soil were made with respect to pH, lime requirement, exchangeable hydrogen, total exchange capacity, and available phosphorus. Plant material was weighed to determine yield and analysed for phosphorus content.

The pH determination was made with the standard glass electrode using a soil to water ratio of 1:1. Lime requirement was determined by combining use of the glass electrode and use of a buffered solution at pH 7 as suggested by Woodruff (9). The composition of this buffered solution is a mixture of calcium acetate, P-nitrophenol, and magnesium oxide. The advantage of this buffered solution is that there is not an unfavorable reaction with the soil being tested and the rate of reaction is rapid.

The procedure by Mehlich (2) was used for the determination of exchangeable hydrogen in both the Parsons and Geary soils. Ten grams of soil were placed in a 125 milliliter Erlenmeyer flask and 25 milliliters of the buffer solution (0.5 N barium chloride and 0.2 N triethanolamine) were added. The flask was mixed occasionally by swirling and allowed to stand for one-half hour. The soil solution was filtered slowly. An additional 25 milliliters of buffer solution were used during the filtration. By adding small increments, the soil then was leached with 100 milliliters of the replacement solution (250 grams of barium chloride in four liters of distilled water plus ten milliliters of the buffer solution). An internal indicator, methyl purple, was used and the leachate was titrated with 0.1 N HCl. The titration was checked against a blank containing 50 milliliters of the buffer solution and 100 milliliters of the replacement solution. All calculations were made with this blank determination as a reference. The difference between the titration of the soil and the blank is the milliequivalents of exchangeable hydrogen per 100 grams of soil.

Total cation exchange capacity was determined according to Rendig's (3) method with some modifications. Two gram samples of air dried soil were placed into 100 milliliter centrifuge tubes. The soil was washed once with a 50 milliliter portion of 1 N calcium chloride, twice with 1 N calcium acetate, and once again with 1 N calcium chloride. The soil was resuspended each time by means of a rubber ball plunger attached to an electric motor. The suspension was centrifuged at approximately 2500 rpm for five minutes and the washings were discarded. Thus the soil sample was saturated with calcium ions. The soil sample then was washed once with distilled water and several times with 95% ethyl alcohol until the washings gave no test for chloride. The washings were discarded. The soil was washed four times with 1 N ammonium acetate (adjusted to pH 7.0) to replace the calcium ions. These washings with ammonium acetate were collected in a 250 milliliter volumetric flask and made to volume with 1 N ammonium acetate. Calcium then was determined by means of the Beckman flame photometer.

This same procedure was repeated, using potassium instead of calcium as the saturating ion, and the results were compared.

Exchangeable cations were determined according to the following method. Five gram samples of air dried soil were placed into 100 milliliter centrifuge tubes. The soil was washed four times with 50 milliliter portions of 1 N ammonium acetate. The soil was resuspended each time by means of a rubber ball plunger attached to an electric motor and centrifuged at approximately 2500 rpm for five minutes. The washings were collected in 250 milliliter volumetric flasks and made to volume with 1 N ammonium acetate. Sodium, potassium, magnesium and calcium were determined by means of the Beckman flame photometer.

The colorimetric method of Bray and Kurtz (1) was used to determine available phosphorus. Available phosphorus was extracted from the soil with a solution that was 0.025 N with respect to HCl and 0.03 N with respect to NH_4F. A soil to solution ratio of 1:50 was used in the extraction of available phosphorus.

Greenhouse Technique

Eighty pots each of the Parsons silt loam and Geary silt loam soils were prepared by placing 4,000 grams of soil in each of the one gallon earthenware greenhouse containers. Both coils were treated at four rates (corresponding to 0, 2, 4, and 8 tons per acre of $CaCO_3$) with three soil amendments supplying calcium (chemically pure $CaCO_3$, commercial agricultural limestone, and chemically pure $CaSO_4$). Pure chemicals were obtained from the Chemistry Department and the agricultural limestone was obtained from the State ASC Laboratory. This limestone had passed the state requirements and contained the equivalent of 85.93 percent $CaCO_3$. The amounts used in individual greenhouse containers are shown in Table 1.

Table 1. Amounts of soil amendments used in greenhouse experiment.

Soil Amendment	Rate of Application (tons per acre)	Amount of Soil Amendment Applied to Containers (grams per pot)
Check	–	—
$CaCO_3$	2	8
	4	16
	8	32
Agricultural limestone (85.39% $CaCO_3$)	2	9.37
	4	18.74
	8	37.48
$CaSO_4$	2	13.76
	4	27.52
	8	55.04

Each series of soil amendments was duplicated with one series receiving a commercial grade ammonium phosphate type fertilizer (6-24-24) at the rate of 200 pounds per acre and the other series receiving the fertilizer at the rate of 400 pounds per acre. An ammonium phosphate fertilizer was chosen because the addition of calcium thus was prevented. It was not desired to add calcium at this point because it was under consideration as another variable. Individual treatments were replicated four times.

Alfalfa was planted in the containers and three successive crops were harvested. The plant material was dried and weighed to determine the yields. The plant material also was analyzed for content of phosphorus.

EXPERIMENTAL RESULTS

Effect of Various Treatments on the pH of Parsons Silt Loam and Geary Silt Loam Soils

To study the effect of various treatments on the pH of the two soils, 50 gram samples of the soils were placed in 250 milliliter Erlenmeyer flasks. Equivalent amounts of the soil amendments were added to the soils in the flasks according to the rate of application desired. The amounts of each amendment applied to each sample at the various rates of application are shown in Table 2.

Fifty milliliters of distilled water were added to each flask. The flasks then were placed on a rotary shaker and allowed to shake for twenty-four hours. The pH of the soil and water solution then were determined by the glass electrode method.

Table 2. Amounts of soil amendments used in laboratory experiments.

Equivalent Amount of $CaCO_3$ Applied (tons/acre)	Amount of Soil Amendments (grams/flask)			
	$CaCO_3$	Agr. Limestone	$CaSO_4$	$Ca(OH)_2$
0.5	.025	.029	.043	.0185
1.0	.05	.058	.086	.037
1.5	.075	.087	.129	.0555
2.0	.1	.116	.172	.074
2.5	.125	.145	.215	.0925
3.0	.15	.174	.258	.111
3.5	.175	.203	.301	.1295
4.0	.2	.232	.344	.148
4.5	.225	.261	.387	.1665
5.0	.25	.290	.430	.185

As indicated in Fig. 1 and Fig. 2, the original pH values of both the Parsons silt loam and Geary silt loam soils were 5.5. With the Parsons silt loam soil (Fig. 1) it was noted that the application of pure $CaCO_3$ at the rate of four tons per acre increased the pH from the original 5.5 to a pH of 6.7. Further increases in rate of application caused no appreciable change in pH. The application of agricultural limestone at the rate equivalent to four tons per acre of $CaCO_3$ increased the pH to 6.4. Further increases in rate of application caused no appreciable change in pH. The application of the equivalent of three tons per acre of $CaCO_3$ in the form of $CaSO_4$ lowered the pH from the original 5.5 to a pH of 4.5. Increased rates of application caused no further changes in the pH. The application of $Ca(OH)_2$ in increasing rates caused a nearly constant increase in the pH of the soil. With the use of $Ca(OH)_2$ at a rate equivalent to five tons per acre of $CaCO_3$ the pH was increased from the original 5.5 to a pH of 8.0.

With the Geary silt loam soil (Fig. 2) the results of the application of pure $CaCO_3$ and agricultural limestone were very similar to those obtained on the Parsons silt loam soil. The application of $CaSO_4$ at the rate corresponding to one ton per acre of $CaCO_3$ lowered the pH from the original 5.5 to a pH of 5.0. Increased rates of application equivalent to as much as five tons per acre of $CaCO_3$ lowered the pH only slightly more. Increased rates of application of the $Ca(OH)_2$ caused continuous increases in the pH of the Geary silt loam soil. At the application rate corresponding to five tons per acre of $CaCO_3$ the pH was increased from the original 5.5 to a pH of 8.7.

With both soil materials, it was obvious that both $CaCO_3$ and agricultural limestone were limited in effectiveness insofar as causing a change in soil pH was concerned. The rate of reactivity of each with soil acid obviously was far below that of $Ca(OH)_2$.

To study the effects on the pH of the soil of the application of $CaCO_3$ and subsequent boiling to speed the reaction, pure $CaCO_3$ was added in ton increments up to six tons per acre to soil solutions containing 50 grams of soil and 50 milliliters of distilled water. This work was done in duplicate with one sample being boiled for ten minutes with a reflux condensor. The samples then were placed on a shaker and allowed to shake for 24 hours. The pH of the soil and water solutions then were determined by the glass electrode method. The soils were dried and saved. The results are shown in Figs. 3 and 4.

As indicated in Fig. 3, boiling the untreated sample of Parsons silt loam soil lowered the pH from the original 5.5 to a pH of 5.4. As the rates of application of $CaCO_3$ were increased it was noted that the

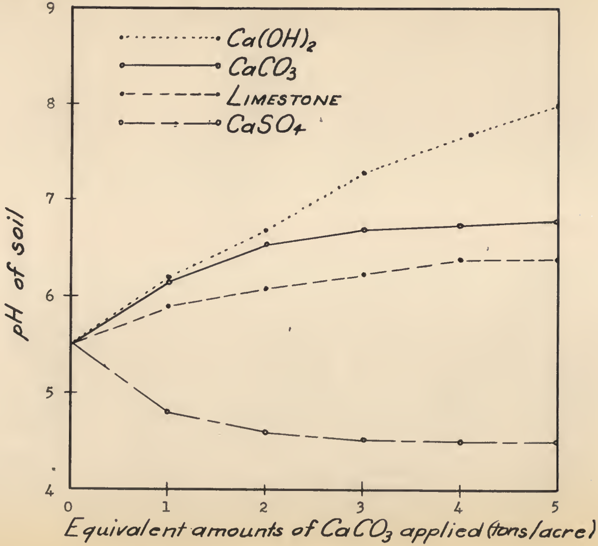

Fig. 1. Effect of various treatments upon the pH of Parsons silt loam soil.

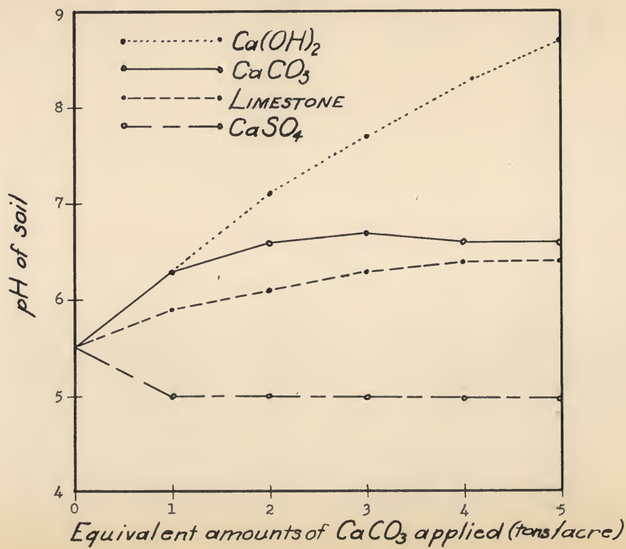

Fig. 2. Effect of various treatments upon the pH of Geary silt loam soil.

boiling caused an increase in pH value over than found in the corresponding unboiled samples. At the 6 ton level of application the pH of the boiled sample was 7.8 as compared to a pH of 6.8 for the unboiled sample.

The effect of the application of $CaCO_3$ and boiling on the pH of the Geary silt loam soil is shown in Fig. 4. It was noted that an appreciable change in pH due to boiling occurred at the two ton rate of application on the Geary silt loam and at the three ton rate of application on the Parsons silt loam soil. At the six ton level of application on the Geary silt loam soil the pH of the boiled sample was 7.9 as compared to a pH of 6.7 for the unboiled sample.

Effect of Boiling and pH on the Phosphorus Status of Parsons Silt Loam and Geary Silt Loam Soils

The colorimetric method of Bray and Kurtz (1) was used to determine the change in available phosphorus content of Parsons silt loam soil following treatment with $CaCO_3$ and boiling. These results are presented in Table 3.

Table 3. Effect of boiling and pH on available phosphorus content of Parsons silt loam soil.

Amount of $CaCO_3$ Added (tons/acre)	Available Phosphorus Content (ppm)		pH of Soil	
	Not Boiled	Boiled	Not Boiled	Boiled
0	5.0	4.2	5.5	5.4
1	4.6	4.1	6.15	6.05
2	4.2	4.4	6.55	6.75
3	5.5	4.6	6.7	7.25
4	5.4	4.8	6.75	7.4
5	4.8	5.1	6.8	7.6
6	5.6	5.2	6.8	7.75

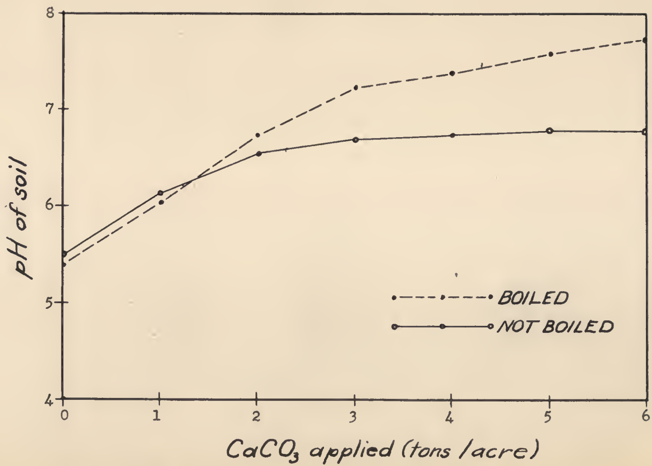

Fig. 3. Effect of $CaCO_3$ application and boiling upon pH of Parsons silt loam soil.

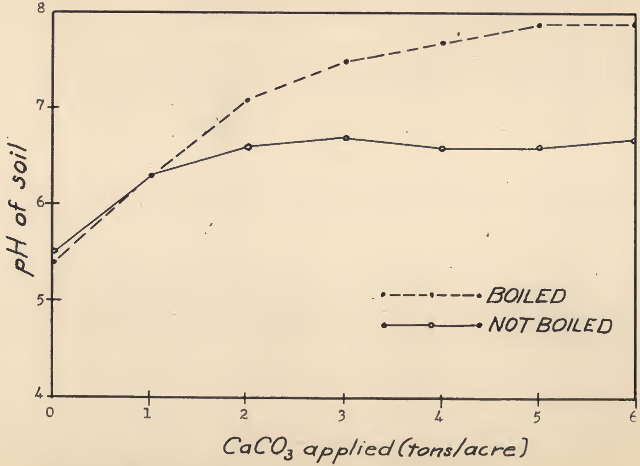

Fig. 4. Effect of $CaCO_3$ application and boiling upon pH of Geary silt loam soil.

It was observed that the available phosphorus content of Parsons silt loam soil was low. It also was noted that boiling and alteration of the pH value had little effect on the amount of available phosphorus.

The effect of boiling and pH on the content of available phosphorus of the Geary silt loam soil is shown in Table 4.

Table 4. Effect of boiling and pH on available phosphorus content of Geary silt loam soil.

Amount of $CaCO_3$ Added (tons/acre)	Available Phosphorus Content (ppm)		pH of Soil	
	Not Boiled	Boiled	Not Boiled	Boiled
0	23.5	22.5	5.5	5.4
1	26.2	25.0	6.3	6.3
2	25.5	25.5	6.6	7.1
3	25.5	28.0	6.7	7.5
4	25.5	30.5	6.6	7.7
5	25.0	26.2	6.6	7.9
6	24.0	25.5	6.7	7.9

It was noted that the available phosphorus content of Geary silt loam was much higher than that of the Parsons silt loam. It also was noted that boiling and changing the pH had little effect on the amount of available phosphorus except where the equivalent of three and four tons per acre of $CaCO_3$ had been applied.

The equivalent of 88.5 ppm of phosphorus in 50 milliliters of water containing dissolved commercial 6-24-24 fertilizer was added to 10 gram samples of soil saved from the pH and boiling experiment. The soil and phosphorus solutions were shaken together for 24 hours and then separated by filtration. Both the soil and filtrate were saved and analyzed colorimetrically for available phosphorus content.

The results of the analyses of the Parsons silt loam soil are shown in Table 5.

Table 5. Effect of boiling and pH on available phosphorus content of Parsons silt loam after addition of 88.5 ppm phosphorus.

Amount of $CaCO_3$ Added (tons/acre)	Available Phosphorus Content (ppm)		pH of Soil	
	Not Boiled	Boiled	Not Boiled	Boiled
0	71.5	69.5	5.5	5.4
1	73.5	67.5	6.15	6.05
2	71.5	71.5	6.55	6.75
3	78.0	80.5	6.7	7.25
4	73.5	82.5	6.75	7.4
5	73.5	73.5	6.8	7.6
6	78.0	80.5	6.8	7.75

It was noted that whenever $CaCO_3$ was added there was a distinct tendency for available phosphorus content to go up. It also was noted where three or more tons of $CaCO_3$ had been applied that after boiling the available phosphorus content was higher. It was at this point that boiling started to affect the pH of the soil following addition of $CaCO_3$.

The results of the analyses of the Geary silt loam are similar as shown by Table 6.

It was noted, however, that the available phosphorus content first increased following boiling after the addition of only two tons of $CaCO_3$ had been made whereas more than three tons of $CaCO_3$ were needed on the Parsons silt loam to get the same effect. It also was noted that where two tons of $CaCO_3$ were added the change in pH of the Parsons silt loam was very small but on the Geary silt loam it was fairly large. This may help explain why Parsons silt loam requires lime so much more than does Geary silt loam.

Table 6. Effect of boiling and pH on available phosphorus content of Geary silt loam after addition of 88.5 ppm phosphorus.

Amount of $CaCO_3$ Added (tons/acre)	Available Phosphorus Content (ppm)		pH of Soil	
	Not Boiled	Boiled	Not Boiled	Boiled
0	85	85	5.5	5.4
1	100	90	6.3	6.3
2	92.5	97.5	6.6	7.1
3	106	112.5	6.7	7.5
4	109	112.5	6.6	7.7
5	106	109	6.6	7.9
6	109	112.5	6.7	7.9

This same effect held to a certain degree for effect of boiling on phosphorus availability. It may be observed that on the Parsons soil the available phosphorus content after boiling ranged from 67.5 ppm at the one ton level to 82.5 ppm at the four ton level. This is a net increase of 15 ppm. On the Geary soil the available phosphorus content ranged from 90 ppm at the one ton level to 112.5 ppm at the three and four ton levels. This is a net gain of 22.5 ppm or 50 percent more than on the Parsons silt loam soil.

It may be observed also that on the unboiled samples the addition of pure $CaCO_3$ from 0 to 3 tons per acre to the Parsons silt loam caused a net variation of only 6.5 ppm of available phosphorus. On the other hand the unboiled Geary soil showed a net gain in available phosphorus of 24 ppm to the application of from 0 to 4 tons of pure $CaCO_3$ per acre. This also suggests that Geary silt loam is easier to improve than Parsons silt loam.

The effects of boiling and pH on the net gain in available phosphorus content of the Parsons silt loam and Geary silt loam soils are found in Tables 7 and 8.

Table 7. Effect of boiling and pH on net gain in available phosphorus content of Parsons silt loam after adding 88.5 ppm phosphorus.

Amount of $CaCO_3$ Added (tons/acre)	Net Gain in Available Phosphorus (ppm)		pH of Soil	
	Not Boiled	Boiled	Not Boiled	Boiled
0	66.5	65.3	5.5	5.4
1	68.9	63.4	6.15	6.05
2	67.3	67.1	6.55	6.75
3	72.5	75.9	6.7	7.25
4	68.1	77.7	6.75	7.4
5	68.7	67.4	6.8	7.6
6	72.4	75.3	6.8	7.75

Table 8. Effect of boiling and pH on net gain in available phosphorus content of Geary silt loam after adding 88.5 ppm phosphorus.

Amount of $CaCO_3$ Added (tons/acre)	Net Gain in Available Phosphorus (ppm)		pH of Soil	
	Not Boiled	Boiled	Not Boiled	Boiled
0	61.5	62.5	5.5	5.4
1	73.8	65.0	6.3	6.3
2	67.0	72.0	6.6	7.1
3	80.5	84.5	6.7	7.5
4	83.5	82.0	6.6	7.7
5	81.0	82.8	6.6	7.9
6	85.0	87.0	6.7	7.9

It is noted in Table 7 that with Parsons silt loam where either three or four tons of $CaCO_3$ were added that following boiling there was a definite increase in available phosphorus (from 72.5 to 75.9 and from 68.1 to 77.7, respectively). The pH values of the soils following boiling were 7.25 and 7.4 respectively, suggesting that these values probably were in the best range for phosphorus availability on the Parsons soil. A pH below this range always coincided with less available phosphorus either on boiled or unboiled soil. There also seemed to be some decrease in phosphorus availability at pH of 7.6 and 7.75.

Net gains in available phosphorus apparently were due to the influence of the soil treatment on the added phosphorus. The amount initially present ranged from 4.1 to 5.6 ppm and was so small as to be quite insignificant in all cases. Soil treatment did not affect these amounts appreciably. Seemingly, the Parsons soil contained so little potentially available phosphorus that more could not be made available.

It may be observed in Table 8 that the same general trends were apparent in the case of the Geary soil as were observed with the Parsons soil. The greatest increases in amount of available phosphorus (from 67 to 72 ppm and 80.5 to 84.5 ppm, respectively) occurred at pH values of 7.1 and 7.5, respectively. This is approximately the same pH range in which the available phosphorus content of the Parsons soil showed an increase.

A solution containing 17.7 ppm of phosphorus was added to the soil at the rate of 50 milliliters to 10 grams of soil. The soil and phosphorus solutions were shaken together for 24 hours and then separated by filtration. The filtrate was saved and analyzed colorimetrically. The results are shown in Figs. 5 and 6.

It may be observed that the amount of available phosphorus remaining in solution decreased steadily as the pH of the soil was elevated after addition of $CaCO_3$ in an amount equivalent to about four tons per acre. The pH value followed this same general trend. Thus it seems that the pH of the soil was a controlling factor.

It was noted that the boiling of either soil lowered the phosphorus fixing capacity. The reason for this is not entirely known at this time. Possibly dehydration of the iron and aluminum hydrates and conversion of

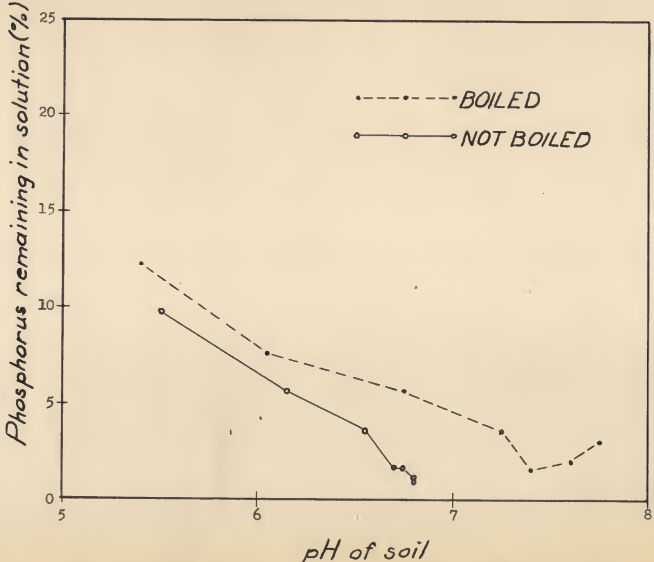

Fig. 5. Influence of boiling and pH on phosphorus content of a water solution in equilibrium with Parsons silt loam. (Solution initially contained 17.7 ppm P).

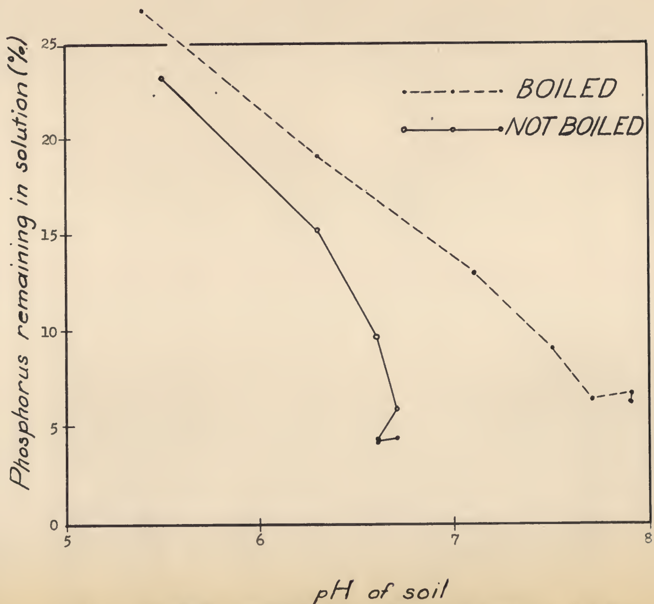

Fig. 6. Influence of boiling and pH on phosphorus content of a water solution in equilibrium with Geary silt loam.

such from non-crystaline to crystaline forms rendered them less active insofar as phosphorus fixation was concerned.

It was observed that the Parsons silt loam allowed only about one-half as much phosphorus to remain in the water solution as compared to the Geary soil. This indicated that Parsons soil presented a less desirable phosphorus relationship since it apparently fixes more of the added phosphorus. On the unboiled Parsons soil the phosphorus relationship was especially bad. In this case the Parsons soil left only about one-third as much phosphorus in solution as did the unboiled Geary soil. The phosphorus fertility situation on the Parsons soil was very poor due to the inability of the soil to maintain appreciable soluble phosphorus even after large additions.

Effect of Boiling and pH on the Lime Requirement of Parsons Silt Loam and Geary Silt Loam Soils

The lime requirements of the Parsons silt loam and Geary silt loam soils were determined by both the Woodruff and exchangeable hydrogen methods. The results, as indicated in Tables 9 and 10, showed that lime requirement as determined by the Woodruff buffer method was lower than that determined by the exchangeable hydrogen method.

A comparison of exchangeable hydrogen content of the unlimed soil materials as determined by three different techniques was possible. The exchangeable hydrogen values of Parsons silt loam as based upon Woodruff's buffer method, as based upon the triethanolamine method of Mehlich, and as calculated by the difference between total cation exchange capacity and the sum of metallic cations were equivalent to 5.0,

Table 9. Effect of boiling and pH upon the lime requirement of Parsons silt loam.

Amount of $CaCO_3$ Applied (tons/acre)	Lime Requirement by Exchangeable Hydrogen Method (pounds/acre)		Lime Requirement by Woodruff Method (pounds/acre)	
	Not Boiled	Boiled	Not Boiled	Boiled
0	8,800	7,800	5,000	5,000
1	6,300	6,600	3,300	3,300
2	5,000	4,900	2,500	2,000
3	3,900	3,500	1,000	1,000
4	2,700	2,800	0	0

Table 10. Effect of boiling and pH upon the lime requirement of Geary silt loam.

Amount of $CaCO_3$ Applied (tons/acre)	Lime Requirement by Exchangeable Hydrogen Method (pounds/acre)		Lime Requirement by Woodruff Method (pounds/acre)	
	Not Boiled	Boiled	Not Boiled	Boiled
0	7,000	6,900	4,000	4,000
1	5,600	4,500	3,000	2,000
2	4,000	3,200	1,500	1,000
3	2,900	2,600	0	0
4	2,300	1,800	0	0

8.8 and 3.5 milliequivalents per 100 grams of soil material, respectively. For the Geary soil, the respective values were equivalent to 4.0, 7.0 and 2.3 milliequivalents per 100 grams of soil.

Comparing these values with the actual amount of milliequivalents of calcium contained in $Ca(OH)_2$ required to render the pH value of the soil neutral revealed that the method of Woodruff gave the closest agreement. The measured lime requirement by the Woodruff method was equivalent to 5,000 pounds per acre of $CaCO_3$ and exactly the equivalent of this amount of $Ca(OH)_2$ gave neutralization for the Parsons soil. For the Geary soil, the measured lime requirement was 4,000 pounds per acre and according to Fig. 2 the actual requirement was 3,800 pounds per acre.

The triethanolamine method indicated values for lime requirement which were too large and the calculation by difference between total cation exchange capacity and sum of metallic cations gave indications which were too low.

Effect of Boiling and pH upon the Exchange Capacity of Parsons Silt Loam and Geary Silt Loam Soils

The exchange capacities of the Parsons silt loam and Geary silt loam soils were determined using both calcium and potassium as the saturating ions. The results, shown in Tables 11 and 12, are very similar in the case of the Parsons silt loam but vary slightly in the case of the Geary silt loam soil.

Table 11. Effect of various treatments upon the exchange capacity of Parsons silt loam soil.

Equivalent Amounts of $CaCO_3$ Applied (tons/acre)	Total Exchange Capacity of Parsons Silt Loam Soil (m.e./100 grams)			
	Using Calcium as the Saturating Ion		Using Potassium as the Saturating Ion	
	Not Boiled	Boiled	Not Boiled	Boiled
0	18.6	18.6	19.2	19.2
1	19.5	19.9	19.6	20.0
2	20.9	21.7	20.3	20.2
3	19.0	17.2	19.6	17.8

Exchangeable metallic cations of the Parsons silt loam and Geary silt loam soils were determined and the results are presented in Table 13.

Table 12. Effect of various treatments upon the exchange capacity of Geary silt loam soil.

Equivalent Amounts of $CaCO_3$ Applied (tons/acre)	Total Exchange Capacity of Geary Silt Loam Soil (m.e./100 grams)			
	Using Calcium as the Saturating Ion		Using Potassium as the Saturating Ion	
	Not Boiled	Boiled	Not Boiled	Boiled
0	17.8	17.8	16.3	15.7
1	19.6	17.9	17.4	16.0
2	19.5	17.6	18.3	16.4
3	19.5	19.2	17.0	17.6

Table 13. Exchangeable cations of the soil material used in the experiment.

Cation	Exchangeable Cations (m.e./100 grams soil)	
	Parsons Silt Loam	Geary Silt Loam
Potassium	.24	.58
Calcium	7.50	9.20
Magnesium	7.00	5.34
Sodium	.37	.36

Effect of Soil Amendments and Fertilizer upon Yield and Phosphorus Content of Alfalfa

Alfalfa yield data for the first crop produced upon Parsons silt loam soil material are recorded in Table 14 and shown graphically in Fig. 7. Analyses of variance for these data are shown in Tables 20 and 21 of the Appendix. Initially it was apparent that effects due to both treatments and blocks were significant. Further analyses of the treatment effects as reported in Table 21 of the Appendix revealed that there was a marked difference between the effects caused by various sources of calcium used in this experiment. For example, use of pure calcium

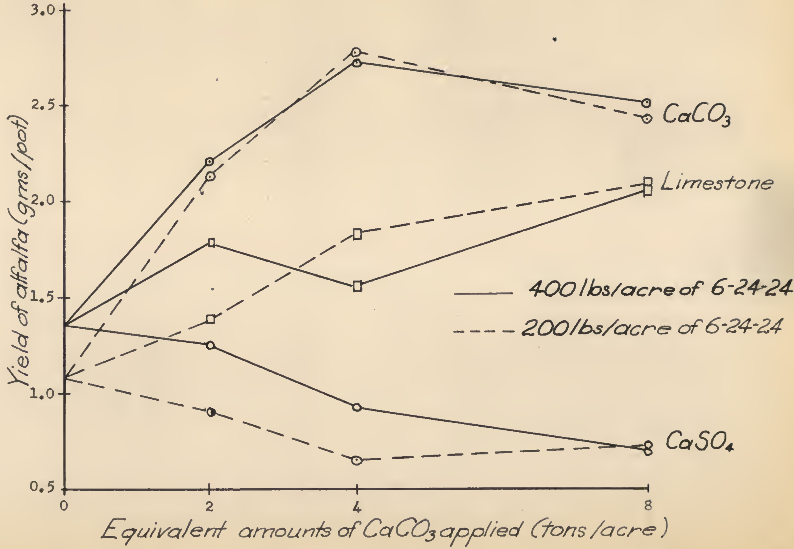

Fig. 7. Influence of soil amendments and fertilizer upon yield of alfalfa grown on Parsons silt loam. (First crop)

Table 14. Effect of soil amendments and fertilizer upon yield of alfalfa, first crop.

Equivalent Amount of $CaCO_3$ (tons/A)	Amount of 6-24-24 Fertilizer (lb./A)	Mean[1] Yield of Plant Material (grams/pot)							
		No Calcium		$CaCO_3$		Limestone		$CaSO_4$	
		Parsons	Geary	Parsons	Geary	Parsons	Geary	Parsons	Geary
0	200	1.08	1.58	—	—	—	—	—	—
0	400	1.35	2.12	—	—	—	—	—	—
2	200	—	—	2.12	2.28	1.38	1.42	.90	2.28
2	400	—	—	2.20	2.42	1.78	2.22	1.25	2.55
4	200	—	—	2.78	2.50	1.82	2.38	.65	2.15
4	400	—	—	2.48	2.20	1.55	2.40	.92	2.35
8	200	—	—	2.42	2.15	2.08	2.58	.72	2.12
8	400	—	—	2.50	2.45	2.05	2.62	.70	2.28

		Parsons	Geary
L.S.D.	(.05)	.39 grams	.44 grams
	(.01)	.52 grams	.58 grams

[1]Mean of four replications.

carbonate produced an average yield of 2.46 grams per pot, use of limestone produced 1.77 grams per pot, and use of calcium sulfate resulted in an average yield of only 0.86 grams per pot. This latter yield was substantially below that obtained where no calcium at all was supplied.

These analyses of variance for the above yield data also indicated that neither rate of application of fertilizer, level of application of calcium, the interaction of rates of fertilizer and levels of application of calcium, the interaction of rates of application of fertilizer and sources of calcium, nor the interaction between rates of fertilizer, levels of added calcium and sources of calcium had significant effect upon yields of alfalfa. There was, however, a significant interaction between levels of application of fertilizer and sources of calcium because two sources, calcium carbonate and limestone, caused yield increases whereas the other source, calcium sulfate, caused a decrease in yield.

Yield data for the first crop produced upon Geary silt loam are recorded in Table 14 and shown graphically in Fig. 8. Analyses of variance for these data are shown in Tables 22 and 23 of the Appendix. Initially, it was apparent that effects due to both treatments and blocks were significant. It was noted that the application of calcium increased the yield over treatments where no calcium was applied.

The analyses of variance for the various treatment effects show that the level of calcium application, the source of calcium, the interaction of rates of application of fertilizer and levels of calcium application, the interaction of rates of application of fertilizer and sources of calcium, and the interaction between rates of fertilizer, levels of calcium application and sources of calcium did not have significant effect upon the yield of alfalfa. However, the rates of fertilizer application and the interaction between levels and sources of calcium did have significant effect upon the yield.

Alfalfa yield data for the second cutting produced upon Parsons silt loam soil are recorded in Table 15 and shown graphically in Fig. 9. Analyses of variance of these data are shown in Tables 24 and 25 of the Appendix. It was noted that effects due to both treatments and blocks were significant. The rates of fertilizer application varied significantly where no calcium was applied, but not for the various other calcium treatments. The analyses of variance of the treatment effects revealed that neither the interaction of rates of fertilizer and levels of calcium, the interaction of rates of fertilizer and source of calcium,

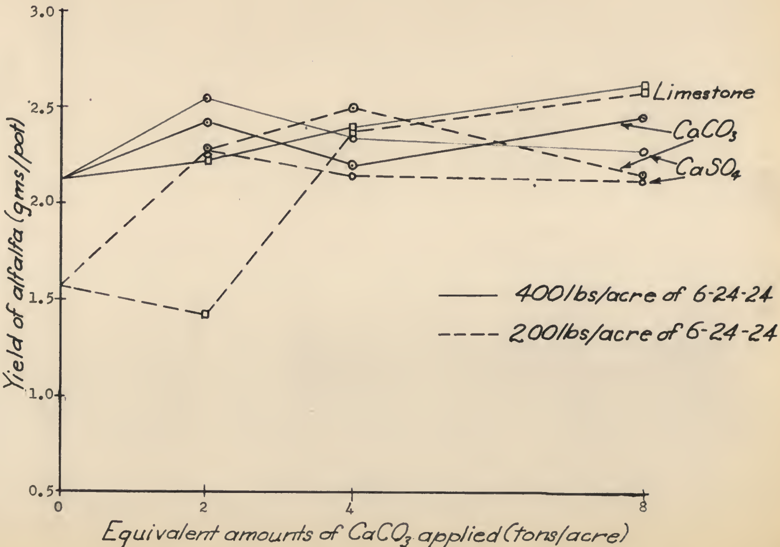

Fig. 8. Influence of soil amendments and fertilizer upon yield of alfalfa grown on Geary silt loam. (First crop)

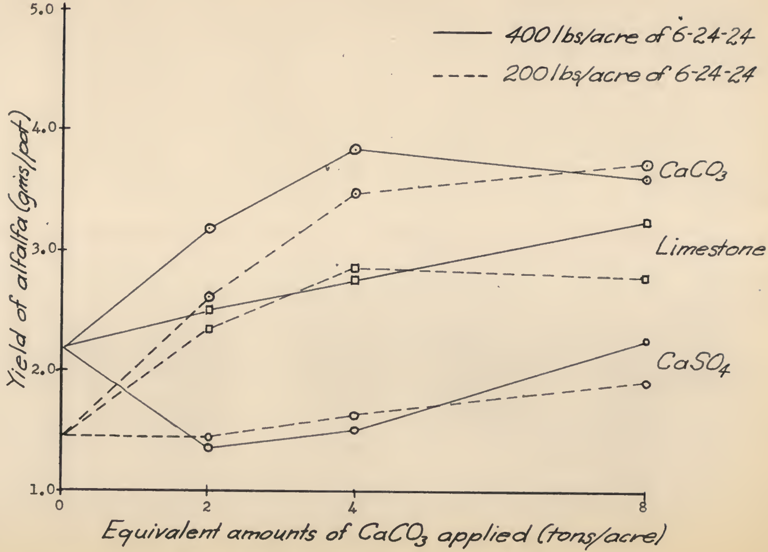

Fig. 9. Influence of soil amendments and fertilizer upon yield of alfalfa grown on Parsons silt loam. (Second crop)

Table 15. Effect of soil amendments and fertilizer upon yield of alfalfa, second crop.

Equivalent Amount of $CaCO_3$ (tons/A)	Amount of 6-24-24 Fertilizer (lb./A)	Mean[1] Yield of Plant Material (grams/pot)							
		No Calcium		$CaCO_3$		Limestone		$CaSO_4$	
		Parsons	Geary	Parsons	Geary	Parsons	Geary	Parsons	Geary
0	200	1.42	3.32	—	—	—	—	—	—
0	400	2.15	3.78	—	—	—	—	—	—
2	200	—	—	2.62	4.50	2.35	3.12	1.45	3.55
2	400	—	—	3.20	4.05	2.52	4.05	1.35	3.60
4	200	—	—	3.50	5.10	2.88	4.40	1.62	3.70
4	400	—	—	3.90	4.22	2.78	4.60	1.52	4.10
8	200	—	—	3.78	4.32	2.82	4.40	1.92	3.52
8	400	—	—	3.65	4.28	3.28	4.30	2.25	3.50

		Parsons	Geary
L.S.D.	(.05)	.71 grams	.74 grams
	(.01)	.95 grams	.98 grams

[1]Mean of four replications.

the interaction of levels and sources of calcium, nor the interaction of rates of fertilizer, levels of calcium and sources of calcium had significant effect upon the yield. The effects due to levels of calcium and sources of calcium were significant. It was noted that limestone and pure calcium carbonate caused increases in yield. It also was noted that calcium sulfate did not have the depressing effect on yield that was so pronounced in the first cutting.

Yield data for the second cutting of alfalfa produced upon Geary silt loam, as recorded in Table 15 and shown graphically in Fig. 10, indicated that the application of calcium tended to increase the yield. Analyses of variance of these data are shown in Tables 26 and 27 of the Appendix. It was noted that effects due to treatments and blocks were both significant.

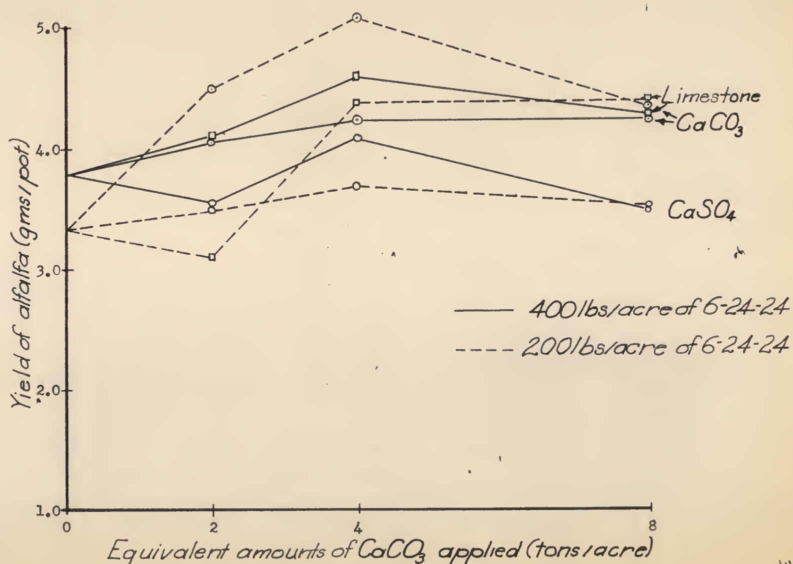

Fig. 10. Influence of soil amendments and fertilizer upon yield of alfalfa grown on Geary silt loam. (Second crop)

From the analyses of variance of the treatment effects it was noted that the rates of fertilizer application, the interaction of the rates of fertilizer and levels of calcium, the interaction of the levels and sources of calcium did not have significant effect upon the yields of alfalfa. However, the levels of calcium application, the sources of calcium and the interaction between rates of fertilizer application and sources of calcium did have significant effect upon the yield of alfalfa.

Table 16 and Fig. 11 show the yield data for the third cutting of alfalfa grown on Parsons silt loam. Tables 28 and 29 of the Appendix show the analyses of variance of these data. Effects due to both treatments and blocks were significant. It was observed that the application of calcium from any of the three sources resulted in an increase in yield. From the analyses of variance of the treatment effects it was noted that effects due to levels of calcium applied, sources of calcium, and the interaction between levels and sources of calcium were all significant. Other effects and interaction of effects were not significant.

In Table 16 and Fig. 12 are shown the yield data for the third cutting of alfalfa grown on Geary silt loam. The analyses of variance of these data are recorded in Tables 30 and 31 of the Appendix. Effects due to treatments and blocks were significant. It was noted that the application of calcium up to four tons per acre tended to increase the yield. From the analyses of variance of the treatment effects it was noted that effects due to rates of fertilizer application, levels of calcium application, the interaction of rates of fertilizer and levels of calcium applied, and the interaction of levels and sources of calcium

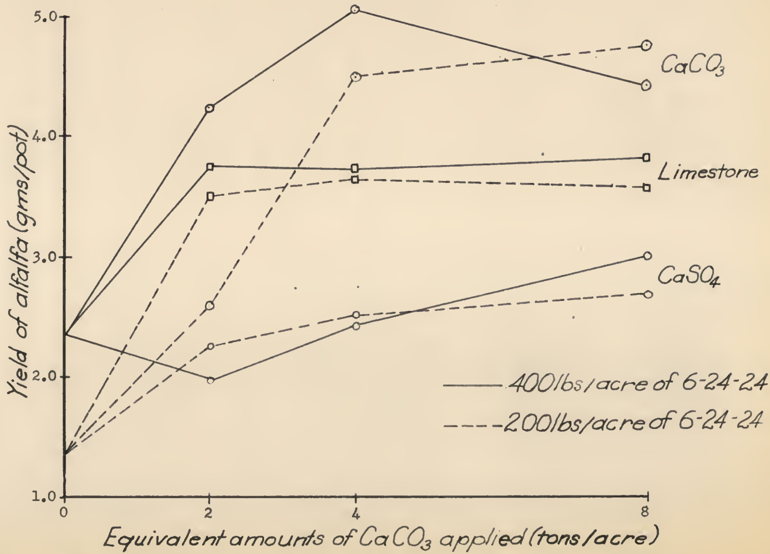

Fig. 11. Influence of soil amendments and fertilizer upon yield of alfalfa grown on Parsons silt loam. (Third crop)

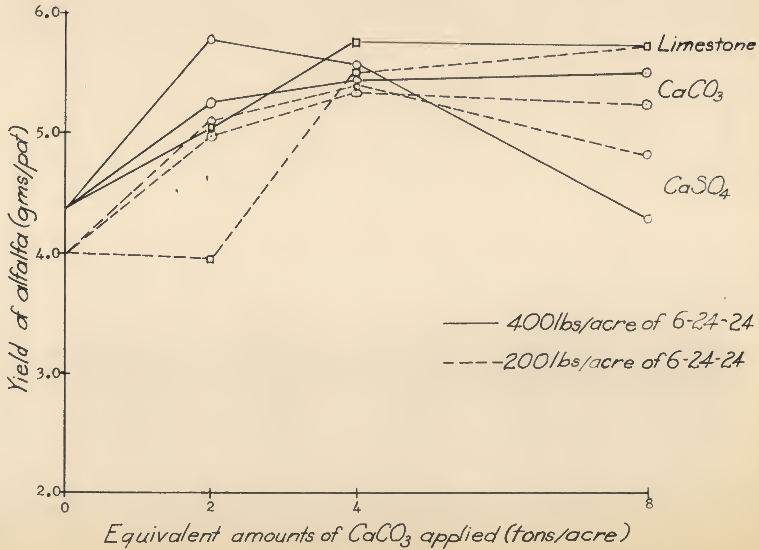

Fig. 12. Influence of soil amendments and fertilizer upon yield of alfalfa grown on Geary silt loam. (Third crop)

Table 16. Effect of soil amendments and fertilizer upon yield of alfalfa, third crop.

Equivalent Amount of $CaCO_3$ (tons/A)	Amount of 6-24-24 Fertilizer (lb./A)	Mean[1] Yield of Plant Material (grams/pot) No Calcium Parsons	No Calcium Geary	$CaCO_3$ Parsons	$CaCO_3$ Geary	Limestone Parsons	Limestone Geary	$CaSO_4$ Parsons	$CaSO_4$ Geary
0	200	1.38	4.00	—	—	—	—	—	—
0	400	2.38	4.38	—	—	—	—	—	—
2	200	—	—	2.60	4.95	3.50	3.95	2.28	5.08
2	400	—	—	4.22	5.25	3.78	5.05	1.98	5.80
4	200	—	—	4.50	5.32	3.65	5.45	2.52	5.42
4	400	—	—	5.05	5.42	3.72	5.75	2.42	5.48
8	200	—	—	4.78	5.22	3.58	5.72	2.70	4.90
8	400	—	—	4.40	5.48	3.82	5.72	3.00	4.30

		Parsons	Geary
L.S.D.	(.05)	.95 grams	.63 grams
	(.01)	1.26 grams	.84 grams

[1]Mean of four replications.

all were significant. Other treatment effects or interaction of treatment effects were not significant.

The phosphorus content data for the first cutting of alfalfa grown on Parsons silt loam, as recorded in Table 17 and shown graphically in Fig. 13, indicate that the application of calcium greatly affected the phosphorus content of the plant material. Analyses of variance for these data are shown in Tables 32 and 33 of the Appendix. Effects due to the treatments were significant but there were no significant differences between the blocks. Analyses of the treatment effects revealed that there were marked differences between the effects caused by the various sources of calcium. It was noted that both the use of pure calcium carbonate and the use of limestone increased the phosphorus content of the plant material while the use of calcium

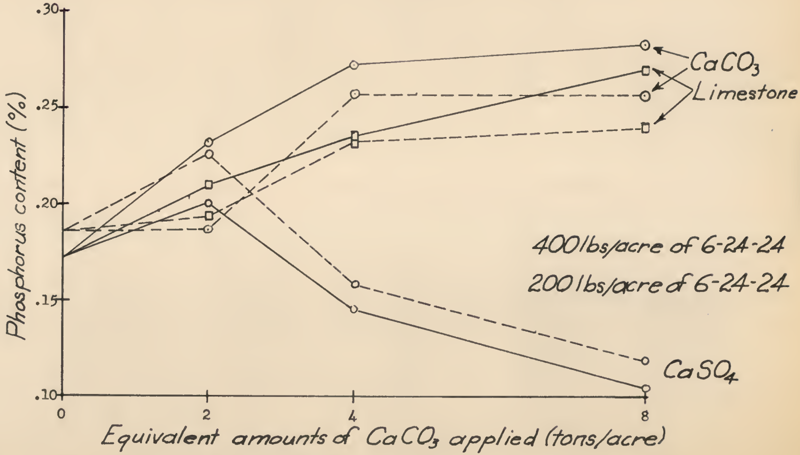

Fig. 13. Influence of soil amendments and fertilizer upon phosphorus content of alfalfa grown in Parsons silt loam. (First crop)

Table 17. Effect of soil amendments and fertilizer upon phosphorus content of alfalfa, first crop.

Equivalent Amount of $CaCO_3$ (tons/A)	Amount of 6-24-24 Fertilizer (lb./A)	Mean[1] Phosphorus Content of Plant Material (%)							
		No Calcium		$CaCO_3$		Limestone		$CaSO_4$	
		Parsons	Geary	Parsons	Geary	Parsons	Geary	Parsons	Geary
0	200	.186	.198	—	—	—	—	—	—
0	400	.172	.216	—	—	—	—	—	—
2	200	—	—	.187	.244	.194	.194	.226	.240
2	400	—	—	.232	.226	.210	.250	.202	.238
4	200	—	—	.258	.240	.233	.270	.159	.232
4	400	—	—	.274	.253	.235	.240	.145	.228
8	200	—	—	.257	.256	.240	.264	.120	.220
8	400	—	—	.284	.240	.270	.270	.105	.229

		Parsons	Geary
L.S.D.	(.05)	.052%	.032%
	(.01)	.069%	.043%

[1]Mean of four replications.

sulfate lowered the phosphorus content as compared to the treatment where no calcium was applied.

The analyses of variance of the treatment data revealed that the interaction between rates of fertilizer application and levels of calcium application and the interaction between rates of fertilizer, levels of calcium and source of calcium did not have significant effect on the phosphorus content of the alfalfa. There were, however, significant effects due to rates of fertilizer, level of calcium application, source of calcium, the interaction of rates of fertilizer and source of calcium, and the interaction between levels and sources of calcium.

The phosphorus content data for the first cutting of alfalfa grown in the Geary silt loam soil are recorded in Table 17 and shown graphically in

Fig. 14. Analyses of variance for these data are shown in Tables 34 and 35 of the Appendix. It is noted that the treatment effects are significant but that the block effects are not significant. It was observed that the application of calcium tended to increase phosphorus content.

The analyses of variance for the treatment effects indicated that neither rate of application of fertilizer, level of calcium application, the interaction of rates of fertilizer and levels of calcium application, nor the interaction between rates of fertilizer and sources of calcium had significant effect upon the phosphorus content of the alfalfa. However, there were significant effects due to sources of calcium, interaction between levels and sources of calcium, and interaction of rates of fertilizer, levels of calcium and source of calcium.

From the phosphorus content data, as recorded in Table 18 and shown graphically in Fig. 15, it was observed that the application of calcium tended to decrease the phosphorus content of the second cutting of alfalfa produced upon Parsons silt loam soil. The effect on phosphorus content of the alfalfa due to the rates of application of fertilizer was significant on treatments where calcium had been applied but was not significant on the treatment where no calcium was applied. The analyses of variance are shown in Tables 36 and 37 of the Appendix. It was noted that treatment effects were significant and that block effects were not significant. From the analyses of variance of the treatment effects, it was observed that neither the levels of calcium, sources of calcium, interaction between rates of fertilizer application and levels of calcium application, interaction between rates of fertilizer

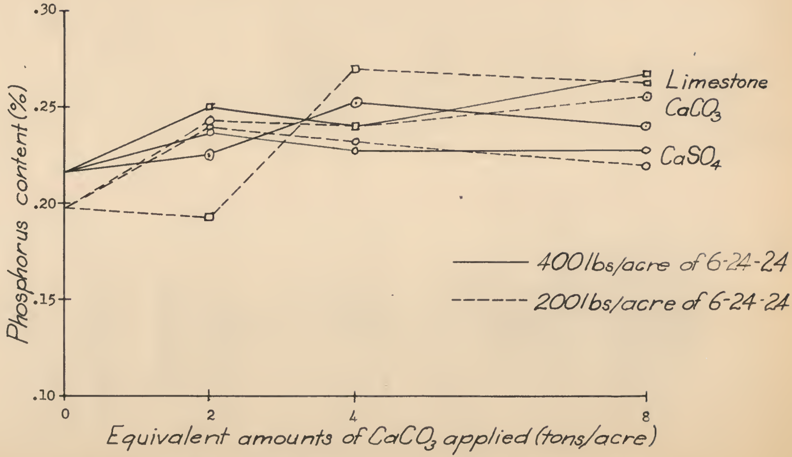

Fig. 14. Influence of soil amendments and fertilizer upon phosphorus content of alfalfa grown on Geary silt loam. (First crop)

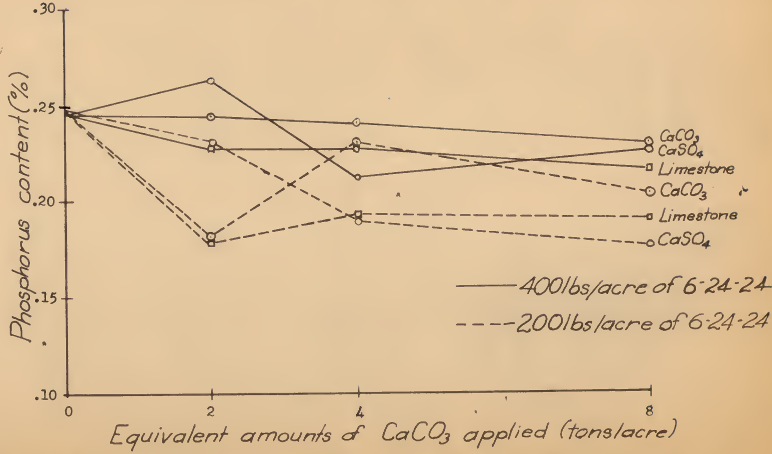

Fig. 15. Influence of soil amendments and fertilizer upon phosphorus content of alfalfa grown in Parsons silt loam. (Second crop)

Table 18. Effect of soil amendments and fertilizer upon phosphorus content of alfalfa, second crop.

Equivalent Amount of $CaCO_3$ (tons/A)	Amount of 6-24-24 Fertilizer (lb./A)	Mean[1] Phosphorus Content of Plant Material (%)							
		No Calcium		$CaCO_3$		Limestone		$CaSO_4$	
		Parsons	Geary	Parsons	Geary	Parsons	Geary	Parsons	Geary
0	200	.247	.171	--	--	--	--	--	--
0	400	.244	.174	--	--	--	--	--	--
2	200	--	--	.182	.169	.180	.205	.230	.186
2	400	--	--	.244	.179	.228	.223	.264	.218
4	200	--	--	.230	.258	.194	.222	.192	.219
4	400	--	--	.240	.253	.230	.220	.213	.242
8	200	--	--	.203	.259	.190	.224	.177	.234
8	400	--	--	.229	.268	.216	.226	.226	.229

		Parsons	Geary
L.S.D.	(.05)	.045%	.023%
	(.01)	.060%	.031%

[1]Mean of four replications.

application and source of calcium, nor the interaction of rates of fertilizer, levels of calcium and source of calcium had significant effect upon the phosphorus content of the alfalfa. The effects of rates of fertilizer application, and the interaction between levels and sources of calcium were significant, however.

Phosphorus content data for the second cutting of alfalfa produced upon Geary silt loam soil are recorded in Table 18 and shown graphically in Fig. 16. Analyses of variance for these data are shown in Tables 38 and 39 of the Appendix. Effects due to treatments and blocks were significant. It was noted that the application of calcium tended to increase the phosphorus content of the alfalfa. From the analysis of variance of the treatment effects it was noted that neither the interaction of the rates of fertilizer application and the levels of calcium application, the interaction between

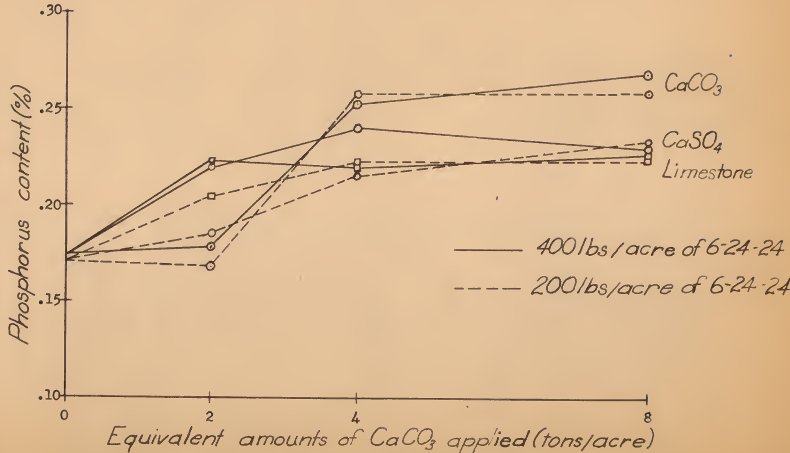

Fig. 16. Influence of soil amendments and fertilizer upon phosphorus content of alfalfa grown in Geary silt loam. (Second crop)

the rates of fertilizer and sources of calcium, nor the interaction between rates of fertilizer, levels of calcium and sources of calcium had significant effect upon the phosphorus content of the alfalfa. It was noted, however, that effects due to rates of fertilizer, levels of calcium, sources of calcium, and interaction between levels and sources of calcium were significant.

Phosphorus content data for the third cutting of alfalfa grown on Parsons silt loam soil are shown by Table 19 and Fig. 17. The analyses of variance of these data are shown in Tables 40 and 41 of the Appendix. It was noted that effects due to treatments were significant while effects due to blocks were not significant. From the analyses of variance of the treatment data it was observed that the effects of rates of fertilizer application and sources of calcium were significant. Other treatment effects and interactions of treatment effects were not significant.

Table 19 and Fig. 18 show the phosphorus content data for the third cutting of alfalfa grown on Geary silt loam soil. The analyses of variance of these data are shown in Tables 42 and 43 of the Appendix. It was noted that effects due to both treatments and blocks were significant. The phosphorus content, when averaged over all rates of fertilizer application, levels of calcium application, and sources of calcium is the same as at the treatment where no calcium was applied. However, from the analyses of variance of the treatment data it was noted that the effects due to rates of fertilizer application, levels of calcium application, and sources of calcium were significantly different. Also,

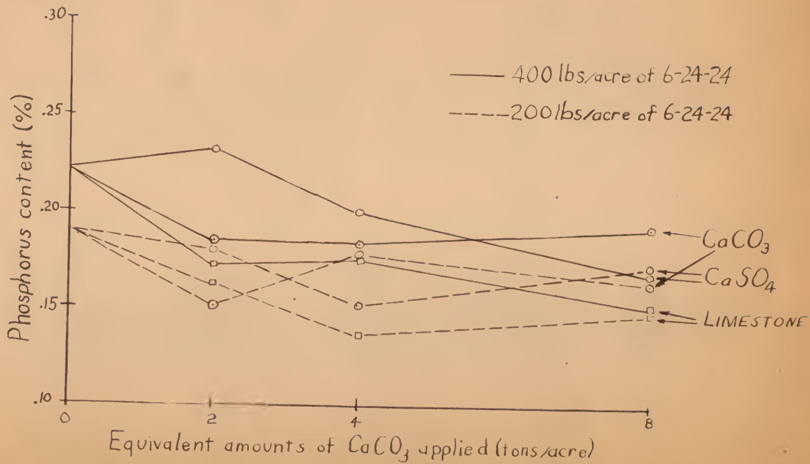

Fig. 17. Influence of soil amendment and fertilizer upon phosphorus content of alfalfa grown in Parsons silt loam. (Third crop)

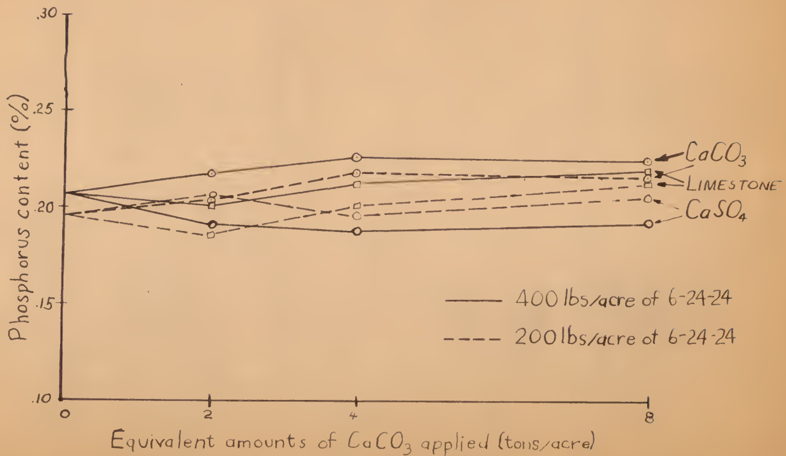

Fig. 18. Influence of soil amendments and fertilizer upon phosphorus content of alfalfa grown in Geary silt loam. (Third crop)

Table 19. Effect of soil amendments and fertilizer upon phosphorus content of alfalfa, third crop.

Equivalent Amount of $CaCO_3$ (tons/A)	Amount of 6-24-24 Fertilizer (lb./A)	Mean[1] Phosphorus Content of Plant Material (%)							
		No Calcium		$CaCO_3$		Limestone		$CaSO_4$	
		Parsons	Geary	Parsons	Geary	Parsons	Geary	Parsons	Geary
0	200	.190	.196	--	--	--	--	--	--
0	400	.221	.207	--	--	--	--	--	--
2	200	--	--	.151	.204	.163	.186	.181	.192
2	400	--	--	.185	.217	.173	.204	.232	.204
4	200	--	--	.179	.218	.136	.201	.152	.196
4	400	--	--	.184	.226	.177	.213	.200	.189
8	200	--	--	.164	.216	.148	.214	.172	.206
8	400	--	--	.192	.225	.152	.219	.169	.192

		Parsons	Geary
L.S.D.	(.05)	.040%	.018%
	(.01)	.053%	.024%

[1]Mean of four replications.

it was observed that the interaction of these treatment effects were not significant.

DISCUSSION

As a result of the collection of data in this investigation; it was possible to provide answers, at least in part, for the questions raised in the statement of objectives at the outset of this research.

In the case of the first objective, the purpose was to determine why large amounts of limestone did not cause comparably large changes in pH of Parsons silt loam at the Thayer Experiment Field. This question was raised because it had been observed that application of eight tons per acre of limestone in 1954 was necessary for satisfactory growth of alfalfa in 1955.

Inasmuch as it seemed completely unlikely that this amount was actually needed to neutralize the acidity present in the soil this first objective was set forth. As has been observed earlier in connection with Fig. 1, applying $Ca(OH)_2$ at a rate equivalent to 2.5 tons per acre of $CaCO_3$ effected neutralization of the soil. It was apparent that if a comparatively soluble and reactive form of lime was used that neutralization was accomplished with only a modest rate of liming. However, use of ground limestone at a rate equivalent to four tons per acre of $CaCO_3$ caused the pH to rise only to 6.4. This no doubt was due to the low rate of reactivity of limestone with the soil and due to the insolubility of this substance. Even with the use of as much as five tons per acre of precipitated $CaCO_3$, it was not possible to accomplish neutralization of the soil under laboratory conditions.

It was obvious from these results that difficulty in correcting natural soil acidity in the Parsons soil under field conditions is not due to an especially high lime requirement of the soil itself but due rather to the low rate of reactivity that agricultural limestone has with the acidity of such soil.

In order to more fully substantiate this deduction, that part of the experiment involving boiling was undertaken. The specific purpose of boiling the mixture of soil and $CaCO_3$ was to hasten the rate of reaction between the $CaCO_3$ and the soil acidity. This treatment obviously accomplished the purpose because $CaCO_3$ after such boiling became essentially as effective as $Ca(OH)_2$ insofar as neutralizing acidity of the Parsons soil material was concerned.

Similar observations were made with the Geary soil because this soil, despite its characteristic acidity, has long been an excellent growth medium for alfalfa. The suitability of this soil for alfalfa production has been demonstrated at the Agronomy Farm where alfalfa has been grown at intervals on the various fields for nearly fifty years despite the lack of use of limestone. The Geary soil proved to require less $Ca(OH)_2$ for neutralization than did the Parsons soil. Otherwise the behavior of the various liming materials was similar as observed for the Parsons soil material. No doubt the relatively greater suitability of the unlimed Geary soil for alfalfa production has been associated in part with its lower lime requirement for neutralization of soil acidity, despite the fact that both materials possessed the same measured pH value. The Geary soil required the equivalent of only 1.9 tons per acre of $CaCO_3$ (using either $Ca(OH)_2$ of using $CaCO_3$ followed by boiling) for complete neutralization.

In order to understand more intelligently the differences that prevail with respect to Parsons and Geary soils insofar as growth of alfalfa is concerned, the second objective dealt with a consideration of alfalfa growth and phosphorus availability of the two soil materials.

Alfalfa growth was quite unsatisfactory on unlimed Parsons soil material. The total yield for three cuttings was 3.83 grams per pot where only 200 pounds per acre of the 6-24-24 fertilizer were used and 5.88 grams per pot where 400 pounds per acre of the same fertilizer were used. These yields when converted to an acre basis were equivalent to approximately 1.0 and 1.5 tons, respectively. On the other hand the unlimed Geary material produced the equivalents of nearly 2.25 tons and over 2.5 tons per acre, respectively, for the same fertilizer treatments. Parsons soil, after adequate treatment with $CaCO_3$, yielded the equivalent of almost three tons per acre of alfalfa and compared favorably with the Geary soil in this respect where top yields for the three cuttings also amounted to about three tons per acre.

It was interesting to note that maximum yield of alfalfa on the Parsons material resulted from the use of the equivalent of four tons per acre of $CaCO_3$ and the use of 400 pounds per acre of 6-24-24 fertilizer. However, with the Geary soil essentially maximum yield of alfalfa for the total of the three cuttings occurred with the use of only two tons per acre of $CaCO_3$ and with the use of only 200 pounds per acre of the fertilizer. These yield data also indicated the lesser need for lime with the Geary soil than was true with the Parsons soil. For example, where 400 pounds per acre were employed, unlimed Geary soil produced a yield equivalent to 83 percent of that obtained after use of two tons per acre of $CaCO_3$. However, with the Parsons material the unlimed soil that had the same fertilizer treatment yielded only 51 percent as much as did the soil which had been treated with four tons per acre of $CaCO_3$.

Phosphorus availability was at a lower level in Parsons soil material than was the case with the Geary soil. This was indicated by chemical extraction of both untreated Parsons soil material and of treated soil material. The level of availability was so low in untreated soil that it was rather apparent that phosphorus supplying power of such was quite inadequate for alfalfa. The net gain in availability of phosphorus after addition of a given amount of phosphorus was less for the Parsons soil than was true for the Geary. This advantage for the Geary soil was especially evident after addition of considerable $CaCO_3$. Greater phosphate fixing ability for the Parsons soil was suggested because after contact of this soil with an aqueous solution of phosphate there was much less left in solution than was true in the case of Geary. Every consideration of chemical availability of phosphorus suggested the greater phosphorus problem which was apparent with the Parsons soil material.

Phosphorus accumulation by alfalfa was greatly improved in the case of plants grown on Parsons soil material as a result of addition of $CaCO_3$. Where only 200 pounds per acre of 6-24-24 fertilizer were used, the total uptake of phosphorus on soil which had been treated with four tons per acre of $CaCO_3$ was increased nearly three-fold. These effects were much less pronounced with alfalfa grown on Geary soil. This lack of effect on Geary soil was due to the fact that considerable phosphorus was accumulated on the unlimed soil due to good growth of the alfalfa.

The beneficial effects of application of $CaCO_3$ upon growth of alfalfa upon the Parsons soil can be attributed only in part to the change in pH of the soil which occurred. That pH of soil was only part of the problem involved already had been suggested by a simple comparison of Parsons and Geary soil since these two were alike with respect to pH but unlike with respect to ability to grow alfalfa on the unlimed soil. Addition of $CaCO_3$ to Parsons soil may have had more favorable effect because this soil had a lesser content of exchangeable Ca to start with. Possibly the exchangeable Ca content of Parsons soil which represented slightly less than half of the metallic cation content and which occupied only about 40 percent of the cation exchange capacity was simply inadequate for either growth of alfalfa or maintenance of phosphate availability which was adequate for this crop. On the other hand, exchangeable Ca content of Geary soil accounted for about 60 percent of the metallic cations and occupied about 55 percent of the total cation exchange capacity. It was entirely likely that this difference was sufficient to account for the unfavorable phosphorus availability which prevailed in the case of Parsons soil. The need of additional research to clarify this point was apparent.

Despite the very unfavorable effect application of $CaSO_4$ had on pH of the soil, especially in the case of Parsons soil, there still was evidence that increasing the calcium supply by this method had a beneficial effect with the Parsons soil material. Actually the unfavorable effect was much more in evidence during the production of the first crop than was true later. Alfalfa growing on Parsons soil which was treated with $CaSO_4$ appeared sickly during the first growth period and yielded less as the rate of $CaSO_4$ addition was increased. However, later crops both showed significant responses in yield to heavier applications of $CaSO_4$ on the Parsons soil. Generally speaking, application of $CaSO_4$ to the Geary soil at rates which supplied calcium equivalent to that supplied by either two or four tons per acre of $CaCO_3$ had about the same beneficial effect on yield as did use of $CaCO_3$. The heaviest application of $CaSO_4$ on Geary soil was without benefit, however. Since application of $CaSO_4$ to Geary soil did not lower the pH nearly so much as was true when it was applied to Parsons soil, it was understandable why the growth of alfalfa was not affected so adversely in the case of the first crop. Since such treatment did lower the pH to a certain degree and since it seemed to perform almost as favorably as did $CaCO_3$ on the Geary soil, it must again be concluded that increasing the calcium supply had a favorable effect independent of that attributable to a simple change in pH of the soil.

The final objective of this study was to determine what effect hastening of reaction between $CaCO_3$ and soil acidity with its attendant influence on soil pH had with respect to phosphorus availability. First of all, as has already been stated, hastening of the above reaction by boiling the soil material and $CaCO_3$ in water rendered the effectiveness of $CaCO_3$ very nearly as great as that of $Ca(OH)_2$. This change in pH was not, however, associated with any marked change in chemical availability of native phosphorus contained in either soil. It did seem to improve the availability status of added phosphorus, however. This was true especially where two or more tons per acre of $CaCO_3$ had been added to Parsons soil and where boiling of the mixture had been employed. The effect was apparent with the Geary soil where as little as one ton of $CaCO_3$ had been used and where boiling also was employed. This again suggested that Geary soil enjoyed a more favorable status for growth of alfalfa than did Parsons soil largely because it is easier to present a favorable phosphorus relationship in the former.

It was apparent, nevertheless; even though much of the problem which prevailed in Parsons soil material was due to phosphorus relationships, that calcium can not be ignored. Addition of phosphorus in the form of ammonium phosphate alone was relatively quite ineffective on the Parsons soil. Even had a calcium phosphate been used, it likely would have been quite ineffective. The amount of calcium so furnished is so small by comparison to the amounts supplied and demonstrated as being necessary in these trials that no great practical significance can be attached to the presence of such in a commercial fertilizer.

SUMMARY AND CONCLUSIONS

In order to summarize these results, it can be said in answer to the original objectives that:

(1) Field applications of agricultural limestone made at the Thayer Experiment Field in 1954 largely failed to correct soil acidity in 1955 because of the low rate of reactivity between the limestone and the soil acidity. Precipitated $CaCO_3$ was made very nearly as effective under laboratory conditions as was $Ca(OH)_2$ when simple boiling was used to hasten the rate of reactivity.

Practical solution to this problem in the field probably can be achieved in part by earlier application of limestone before alfalfa growth is anticipated. Further alleviation should be provided by use of finer grades of limestone to allow for more rapid reaction. If necessary small amounts of more reactive forms of liming materials, as for example, $Ca(OH)_2$ or CaO might also be employed to supply part of the calcium.

(2) The phosphorus fertility situation on the Parsons silt loam was very poor as compared to that which existed with the Geary soil. This was demonstrated in the laboratory in the form of high phosphate fixing capacity. It was demonstrated in the greenhouse by the comparatively poor behavior of phosphatic fertilizer when such was used without application of a calcium containing liming material.

(3) Hastening of chemical reaction between $CaCO_3$ and soil acidity caused this form of liming material to become essentially as effective as $Ca(OH)_2$. Generally speaking reductions in degree of soil acidity and/or accompanying increases in calcium supply in the soil were accompanied by improvement in the availability of phosphorus. This was confirmed by plant growth behavior.

In addition to the answers provided for the original objectives, other useful information was provided:

(1) It was observed that use of the Woodruff buffer solution technique for determination of lime requirement gave results with these two soil materials which agreed remarkably well with actual laboratory trials involving varying additions of $Ca(OH)_2$.

(2) A role of calcium, aside from its usual attendant effects of raising soil pH when added in the hydroxide or carbonate form, was indicated. It was suggested that this role is involved in a nutritional function, probably by rendering phosphorus more available to alfalfa.

ACKNOWLEDGEMENT

The author wishes to express his thanks and sincere appreciation to his major instructor, Dr. F. W. Smith, for his interest and helpful advice in conducting this research problem and the preparation of this thesis.

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APPENDIX

Table 20. Analysis of variance of alfalfa yield data, Parsons silt loam, first cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	46.86	
Between treatments	19	36.69	1.9311***
Between blocks	3	5.78	1.9267***
Error	57	4.39	0.07702

Table 21. Analysis of variance for special treatment effects on yield of alfalfa, Parsons silt loam, first cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	34.84	
Rates of fertilizer	1	.14	.14
Levels of calcium	2	.31	.155
Source of calcium	2	30.94	15.47***
Rates X levels	2	.32	.16
Rates X source	2	.11	.055
Levels X source	4	2.70	.675*
Rates X levels X source	4	.32	.08

Table 22. Analysis of variance of alfalfa yield data, Geary silt loam, first cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	21.30	
Between treatments	19	6.84	.3600***
Between blocks	3	9.03	3.0100***
Error	57	5.43	.09526

Table 23. Analysis of variance for special treatment effects on yield of alfalfa, Geary silt loam, first cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	4.80	
Rates of fertilizer	1	.61	0.61*
Levels of calcium	2	.39	0.195
Source of calcium	2	.05	0.025
Rates X levels	2	.56	0.28
Rates X source	2	.18	0.09
Levels X source	4	2.39	0.5975*
Rates X levels X source	4	.62	0.16

Table 24. Analysis of variance of alfalfa yield data, Parsons silt loam, second cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	74.36	
Between treatments	19	52.50	2.7632***
Between blocks	3	7.40	2.4667***
Error	57	14.46	0.2537

Table 25. Analysis of variance for special treatment effects on yield of alfalfa, Parsons silt loam, second cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	46.30	
Rates of fertilizer	1	.50	0.500
Levels of calcium	2	6.04	3.020***
Source of calcium	2	37.61	18.805***
Rates X levels	2	.09	0.045
Rates X source	2	.17	0.085
Levels X source	4	.89	0.222
Rates X levels X source	4	1.00	0.250

Table 26. Analysis of variance of alfalfa yield data, Geary silt loam, second cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	81.77	
Between treatments	19	18.67	0.9826***
Between blocks	3	47.36	15.7867***
Error	57	15.74	0.2761

Table 27. Analysis of variance for special treatment effects on yield of alfalfa, Geary silt loam, second cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	16.29	
Rates of fertilizer	1	.00	0.00
Levels of calcium	2	2.53	1.765**
Source of calcium	2	6.94	3.470***
Rates X levels	2	.26	0.130
Rates X source	2	2.08	1.040*
Levels X source	4	1.74	0.435
Rates X levels X source	4	1.74	0.435

Table 28. Analysis of variance of alfalfa yield data, Parsons silt loam, third cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	108.96	
Between treatments	19	77.05	4.0553***
Between blocks	3	6.35	2.1167***
Error	57	25.56	0.44842

Table 29. Analysis of variance for special treatment effects on yield of alfalfa, Parsons silt loam, third cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	56.71	
Rates of fertilizer	1	1.20	1.20
Levels of calcium	2	6.17	3.085**
Source of calcium	2	39.13	19.565***
Rates X levels	2	.72	0.36
Rates X source	2	1.27	0.635
Levels X source	4	4.61	1.1525*
Rates X levels X source	4	3.61	0.9025

Table 30. Analysis of variance of alfalfa yield data, Geary silt loam, third cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	90.14	
Between treatments	19	24.56	1.2926***
Between blocks	3	54.09	18.0300***
Error	57	11.49	0.20158

Table 31. Analysis of variance for special treatment effects on yield of alfalfa, Geary silt loam, third cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	16.34	
Rates of fertilizer	1	1.10	1.10*
Levels of calcium	2	2.57	1.285**
Source of calcium	2	.20	0.10
Rates X levels	2	2.13	1.065**
Rates X source	2	.51	0.255
Levels X source	4	8.87	2.2175***
Rates X levels X source	4	.96	0.24

Table 32. Analysis of variance of phosphorus content data, Parsons silt loam, first cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	.278766	
Between treatments	19	.197124	.01037***
Between blocks	3	.005441	.00181
Error	57	.076201	.001337

Table 33. Analysis of variance for special treatment effects on phosphorus content of alfalfa, Parsons silt loam, first cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	.188443	
Rates of fertilizer	1	.001531	.001531***
Levels of calcium	2	.000893	.000446*
Source of calcium	2	.106288	.053144***
Rates X levels	2	.000538	.000269
Rates X source	2	.007108	.003554***
Levels X source	4	.070822	.017706***
Rates X levels X source	4	.001263	.000316

Table 34. Analysis of variance of phosphorus content data, Geary silt loam, first cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	.062323	
Between treatments	19	.032250	.00170**
Between blocks	3	.000792	.00026
Error	57	.029281	.000514

Table 35. Analysis of variance of special treatment effects on phosphorus content of alfalfa, Geary silt loam, first cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	.023492	
Rates of fertilizer	1	.000036	.000036
Levels of calcium	2	.002763	.001382
Source of calcium	2	.003428	.001714*
Rates X levels	2	.001236	.000618
Rates X source	2	.000888	.000444
Levels X source	4	.007318	.0018295*
Rates X levels X source	4	.007823	.0019558**

Table 36. Analysis of variance of phosphorus content data, Parsons silt loam, second cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	.113717	
Between treatments	19	.048956	.002577**
Between blocks	3	.006317	.002106
Error	57	.058444	.001025

Table 37. Analysis of variance for special treatment effects on phosphorus content of alfalfa, Parsons silt loam, second cutting.

Source of variance	Degrees of freedom	Sum of squares	Mean square
Total	17	.042087	
Rates of fertilizer	1	.021459	.021459***
Levels of calcium	2	.002600	.001300
Source of calcium	2	.002861	.0014305
Rates X levels	2	.001962	.000981
Rates X source	2	.000042	.000021
Levels X source	4	.011031	.002758*
Rates X levels X source	4	.002132	.000533

Table 38. Analysis of variance of phosphorus content data, Geary silt loam, second cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	.089123	
Between treatments	19	.069531	.00366
Between blocks	3	.004418	.0014726
Error	57	.015174	.0002662

Table 39. Analysis of variance for special treatment effects on phosphorus content of alfalfa, Geary silt loam, second crop.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	.050344	
Rates of fertilizer	1	.001467	.001467*
Levels of calcium	2	.027552	.013776***
Source of calcium	2	.001774	.000887*
Rates X levels	2	.001163	.0005815
Rates X source	2	.000518	.000259
Levels X source	4	.016692	.004173***
Rates X levels X source	4	.001178	.0002945

Table 40. Analysis of variance of phosphorus content data, Parsons silt loam, third cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	.094201	
Between treatments	19	.043613	.002295**
Between blocks	3	.005236	.001745
Error	57	.045352	.000796

Table 41. Analysis of variance for special treatment effects on phosphorus content of alfalfa, Parsons silt loam, third crop.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	.034036	
Rates of fertilizer	1	.010537	.010537***
Levels of calcium	2	.002564	.001282
Source of calcium	2	.008546	.004273**
Rates X levels	2	.000606	.000303
Rates X source	2	.001899	.000950
Levels X source	4	.005443	.001361
Rates X levels X source	4	.004441	.001110

Table 42. Analysis of variance of phosphorus content data, Geary silt loam, third cutting.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	79	.025193	
Between treatments	19	.010991	.000578**
Between blocks	3	.004495	.001498***
Error	57	.009707	.000170

Table 43. Analysis of variance for special treatment effects on phosphorus content of alfalfa, Geary silt loam, third crop.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	17	.010527	
Rates of fertilizer	1	.000741	.000741*
Levels of calcium	2	.001365	.0006825***
Source of calcium	2	.005397	.0026985***
Rates X levels	2	.000753	.0003765
Rates X source	2	.000649	.0003245
Levels X source	4	.001324	.000331
Rates X levels X source	4	.000298	.0000745

EXPLANATION OF PLATE I

First crop of alfalfa grown on Geary silt loam and Parsons silt loam soils.

Treatments were as follows:

Fig. 1. No Lime—No calcium plus 400 lb./A 6-24-24 fertilizer

Fig. 2. $CaCO_3$—Four tons of pure $CaCO_3$ plus 400 lb./A 6-24-24 fertilizer

PLATE I

Fig. 1

Fig. 2

EXPLANATION OF PLATE II

First crop of alfalfa grown on Geary silt loam and Parsons silt loam soils.

Treatments were as follows:

Fig. 1. Ag Lime--Four tons of agricultural limestone plus 400 lbs./A 6-24-24 fertilizer

Fig. 2. $CaSO_4$--Four tons of pure $CaSO_4$ plus 400 lbs./A 6-24-24 fertilizer

PLATE II

Fig. 1

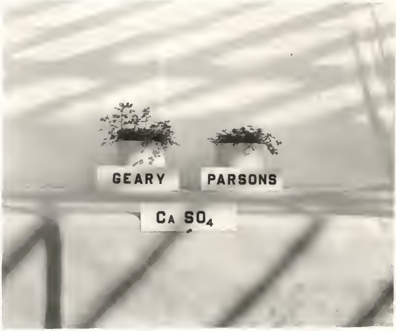

Fig. 2

EXPLANATION OF PLATE III

Fig. 1. First crop of alfalfa grown on Parsons silt loam soil.

Fig. 2. First crop of alfalfa grown on Geary silt loam soil.

Treatments for both soils were as follows:

No Lime--No calcium plus 400 lbs./A 6-24-24 fertilizer

$CaCO_3$--Four tons of pure $CaCO_3$ plus 400 lbs./A 6-24-24 fertilizer

Ag Lime--Four tons of agricultural limestone plus 400 lbs./A 6-24-24 fertilizer

$CaSO_4$--Four tons of pure $CaSO_4$ plus 400 lbs./A 6-24-24 fertilizer

PLATE III

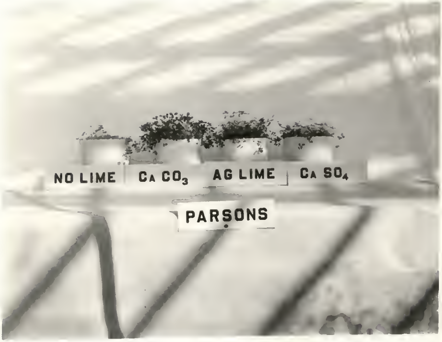

Fig. 1

Fig. 2

EXPLANATION OF PLATE IV

Third crop of alfalfa grown on Geary silt loam and Parsons silt loam soils.

Treatments were as follows:

Fig. 1. No Lime--No calcium plus 400 lbs./A 6-24-24 fertilizer

Fig. 2. $CaCO_3$--Four tons of pure $CaCO_3$ plus 400 lbs./A 6-24-24 fertilizer

PLATE IV

Fig. 1

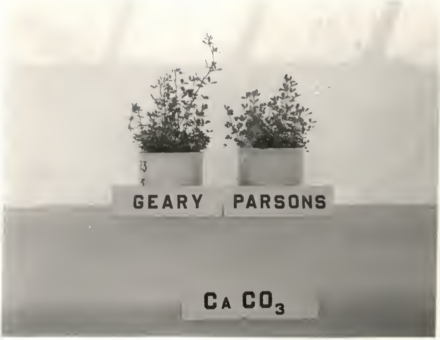

Fig. 2

EXPLANATION OF PLATE V

Third crop of alfalfa grown on Geary silt loam and Parsons silt loam soils.

Treatments were as follows:

Fig. 1. Ag Lime--Four tons of agricultural limestone plus 400 lbs./A 6-24-24 fertilizer

Fig. 2. $CaSO_4$--Four tons of pure $CaSO_4$ plus 400 lbs./A 6-24-24 fertilizer

PLATE V

Fig. 1

Fig. 2

EXPLANATION OF PLATE VI

Fig. 1. Third crop of alfalfa grown on Parsons silt loam soil.

Fig. 2. Third crop of alfalfa grown on Geary silt loam soil.

Treatments for both soils were as follows:

No Lime--No calcium plus 400 lbs./A 6-24-24 fertilizer

$CaCO_3$--Four tons of pure $CaCO_3$ plus 400 lbs./A 6-24-24 fertilizer

Ag Lime--Four tons of agricultural limestone plus 400 lbs./A 6-24-24 fertilizer

$CaSO_4$--Four tons of pure $CaSO_4$ plus 400 lbs./A 6-24-24 fertilizer

PLATE VI

Fig. 1

Fig. 2

EFFECT OF LIMING UPON PHOSPHORUS AVAILABILITY AND GROWTH OF ALFALFA ON PARSONS SILT LOAM AND GEARY SILT LOAM SOILS

by

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B.S., Kansas State College of Agriculture
and Applied Science, 1955

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1956

EFFECT OF LIMING UPON PHOSPHORUS AVAILABILITY AND GROWTH OF ALFALFA ON PARSONS SILT LOAM AND GEARY SILT LOAM SOILS

For the purpose of this study, Parsons silt loam surface soil was obtained from the Experimental Field near Thayer, Kansas, and Geary silt loam surface soil was obtained from the Agronomy Farm near Manhattan, Kansas. Greenhouse pots were filled with 4,000 gram lots of soil material from each source. Calcium treatments corresponding to 0, 2, 4, and 8 tons per acre of $CaCO_3$ were supplied by three soil amendments, including chemically pure $CaCO_3$, commercial agricultural limestone, and chemically pure $CaSO_4$. Each series of soil amendments was duplicated with one series receiving a commercial 6-24-24 ammonium phosphate type of fertilizer at the rate of 200 pounds per acre and the other series receiving the fertilizer at the rate of 400 pounds per acre. Individual treatments were replicated four times. Three crops of alfalfa were produced.

In the laboratory the soils were treated at various rates with several calcium containing soil amendments and the effects on the pH were noted. The initial pH of both the Parsons silt loam and Geary silt loam soils were 5.5. It was observed that if a comparatively soluble and reactive form of lime was used that neutralization was accomplished with only a modest rate of liming since applying $Ca(OH)_2$ at a rate equivalent to 2.5 tons per acre of $CaCO_3$ effected neutralization of the Parsons soil. The use of ground limestone at a rate equivalent to four tons per acre of $CaCO_3$ caused the pH to rise only to 6.4, and it was not possible to accomplish neutralization of the soil under laboratory conditions even with the use of as much as five tons per acre of precipitated $CaCO_3$. However, after boiling the mixture of soil and $CaCO_3$ for ten minutes to hasten the rate of reaction, this treatment became essentially as effective as $Ca(OH)_2$ in neutralizing the acidity of the Parsons silt loam. The application of $CaSO_4$ in an amount equivalent to 5 tons per acre of $CaCO_3$ lowered the pH of the Parsons soil to a value of 4.5.

Similar observations were made with the Geary soil because this soil has long been an excellent growth medium for alfalfa despite its characteristic acidity. The Geary soil required less $Ca(OH)_2$ for neutralization than did the Parsons soil, otherwise, the behavior of the various liming materials was similar as observed for the Parsons soil material. The Geary soil required the equivalent of only 1.9 tons per acre of $CaCO_3$ (using either $Ca(OH)_2$ or using $CaCO_3$ followed by boiling) for complete neutralization. No doubt the relatively greater suitability of the unlimed Geary soil for alfalfa production has been associated in part with its lower lime requirement for neutralization of soil acidity, despite the fact that both soils possessed the same measured pH value.

Phosphorus availability was at a lower level in the Parsons soil material than was the case with the Geary soil. This was indicated by chemical extraction of both untreated and treated samples of both soils. The level of availability was so low in untreated Parsons soil as to be quite inadequate for the growth of alfalfa. Also, the net gain in availability of phosphorus after the addition of a given amount of phosphorus was less for the Parsons soil than for the Geary. This advantage for the Geary soil was especially evident after addition of considerable $CaCO_3$. Greater phosphate fixing ability for the Parsons soil was suggested because after contact of this soil with an aqueous solution of phosphate there was only one-fourth to one-half as much phosphorus remaining in solution as was the case with the Geary soil. Every consideration of chemical availability of phosphorus suggested the greater phosphorus problem which was apparent with the Parsons soil material.

Alfalfa growth was quite unsatisfactory on unlimed Parsons soil material. The total yields for three cuttings were equivalent to 1.0 ton per acre where only 200 pounds per acre of 6-24-24 fertilizer were used and 1.5 tons per acre where 400 pounds per acre of the same fertilizer were used. On the other hand the unlimed Geary soil produced the equivalent of nearly 2.25 tons and over 2.5 tons per acre, respectively, for the same fertilizer treatments. It was noted that maximum yield of alfalfa on the Parsons soil resulted from the use of the equivalent of 4 tons per acre of $CaCO_3$ and 400 pounds per acre of 6-24-24 fertilizer. However, with the Geary soil essentially maximum yield of alfalfa for the total of the three cuttings occurred with the use of only 2 tons per acre of $CaCO_3$ and 200 pounds per acre of the fertilizer. These yield data also indicated the greater need for lime of the Parsons soil as compared to the Geary soil.

Phosphorus accumulation by alfalfa was greatly improved in the case of plants grown on Parsons soil as a result of addition of $CaCO_3$. Where only 200 pounds per acre of 6-24-24 fertilizer were used, the total uptake of phosphorus on soil which had been treated with four tons per acre of $CaCO_3$ was increased nearly three-fold. These effects were much less pronounced with alfalfa grown on Geary soil.

The beneficial effects of application of $CaCO_3$ upon growth of alfalfa on the Parsons soil can be attributed only in part to the change in pH of the soil. Possibly the exchangeable calcium content of Parsons soil which represented less than half of the metallic cation content and occupied only about 40 percent of the cation exchange capacity was inadequate for either growth of alfalfa or maintenance of phosphate availability. On the other hand, exchangeable calcium content of Geary soil accounted for 60 percent of the metallic cations and occupied about 55 percent of the total cation exchange capacity. Also, despite the unfavorable effect application of $CaSO_4$ had on pH of the soil, there still was evidence that increasing the calcium supply by this method had a beneficial effect on the growth of alfalfa. This was true especially with the third crop of alfalfa harvested from Parsons soil.

Briefly, these results indicate that applications of agricultural limestone made at the Thayer Experiment Field in 1954 largely failed to correct soil acidity in 1955 because of the low rate of reactivity between the limestone and the soil. The phosphorus fertility situation on the Parsons silt loam was very poor as compared to the Geary silt loam. Hastening of chemical reaction between $CaCO_3$ and soil acidity caused this form of liming material to become essentially as effective as $Ca(OH)_2$ insofar as neutralization of the soil was concerned.