A COMPARISON OF BASE SATURATION IN SOILS AND THE RESPONSE OF SWEET CLOVER TO LIME

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By

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INTRODUCTION

Many of the soils in central and eastern Oklahoma are acid and are low in available plant nutrients. This condition is due to the leaching effect of rainfall, which is higher in the eastern than in the central part of the state.

Based on the results of over 20,000 tests it would require approximately 10,344,886 tons of limestone to neutralize the acidity in the cultivated soils of Oklahoma.* These tests have been largely qualitative, such as the O.K. (14) and the modified Comber (13) tests, and without special consideration for soil properties such as texture and degree of base saturation.

Limestone applied in excess of soil requirements is subject to leaching; hence it is important to know how much lime would be required to provide optimum conditions for the growth of different legume crops, which vary in degree of acid-tolerance.

It has been found in other states (7, 5, 9, 19) that increased yields of sweet clover and other legumes are not obtained from limestone applications when the degree of base saturation of the soil is 80 percent or higher. This study was made to determine whether or not a similar relationship

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* Harper, H. J., mimeographed bulletin

exists between the response of sweet clover to liming and the degree of base saturation of the exchange complex in Oklahoma soils. If such a relationship exists, the amount of lime required to saturate the base exchange complex to a value of 80 percent may be easily computed. This would be of economic importance in helping to eliminate the waste from applying more lime than was actually necessary to provide favorable conditions for plant growth and the loss of this excess through leaching.

REVIEW OF LITERATURE

Bray and DeTurk (7) found that sweet clover grew well on unlimed soils having a hydrogen-ion concentration between pH 6.5 and 7.0 and a base saturation value of approximately 80 percent. They obtained a good correlation between the pH of the soil and base saturation when the latter value was above 60 percent and the pH value above 5.6.

Bauer (5) found that a number of Illinois soils having a degree of base saturation of 80 percent or above did not show a profitable response to liming when a rotation of wheat, corn, oats and sweet clover was used. On the light-colored, unproductive soils which had a base saturation of less than 80 percent lime applied in both manure and residues systems increased the yield of the common clovers from 300 to 465 percent, while the yield of soybeans varied from 37 to 66 percent.

Naftel (30) obtained maximum growth of Austrian winter peas at 75 percent Ca saturation; maximum growth for vetch was secured with 75-100 percent Ca saturation.

Dunn (9) obtained data which indicate that a soil saturation percentage of about 80 is very favorable for the growth of alfalfa and red clover.

Hull (19) found a correlation between the response of alfalfa to lime and percentage base saturation of Wisconsin soils. On soils where alfalfa responded to liming the base saturation varied from 56.7 to 79 percent, while the pH varied from 5.4 to 6.0.

The general similarity of results obtained by Horner (18) when readily exchangeable ions, such as magnesium and potassium, were substituted for the hydrogen ion of the unsaturated colloidal complex indicates that the variation in the growth of soybeans in moderately acid to strongly acid soils (pH 5.85 to 5.1) is not necessarily related to the variation in the hydrogen-ion concentration, but rather to its concomitant, namely, the degree of calcium saturation.

Powers (34) has shown that certain legumes such as lespedeza sericea, alsike and red clovers are more acid-tolerant than sweet clover.

Albrecht (2) and Horner (18) have obtained results which show that as the calcium saturation of colloidal clay is increased, calcium availability to plants increases not only because of increase in supply of calcium but also because part of the calcium is adsorbed less tightly by the colloidal clay. Horner (18) observed that the calcium in soil colloidal clay, which had a low base saturation was relatively unavailable regardless of the total weight of this nutrient medium used per unit number of plants.

Using two legumes (sweet clover and Korean lespedeza) and two non-legumes (bluegrass and redtop) to determine the effect of degree of saturation of Ca on the intake and delivery of nutrients by a soil, Albrecht and Smith (3) obtained data which emphasized the fact that more nutrients were delivered to these crops because of the higher degree of base saturation in only a limited portion of the soil.

Rost (35) found little correlation between the exchangeable calcium removed by electrodialysis and the response of alfalfa to lime. This may be attributed to the fact that he worked with soils of widely different textures and total exchange capacity. Pierre (33) has suggested that the data obtained by Rost can probably be explained on the basis of percentage base saturation. Two of the soils with which he worked showed nearly the same percentage increase in yield from liming, but more lime was removed from the finer textured soil. It is evident that this larger amount of lime removed from the finer textured soil may represent the same or even a lower degree of saturation than does the smaller amount extracted from the coarser soil.

It appears that plants growing on soils having a high base saturation value have a better opportunity to make a maximum growth because of the greater availability of nutrients since Heck (16) found that a low degree of base saturation tends to give a soil a greater capacity for fixing phosphorus in difficultly available form than if the soil is more fully saturated with bases. Minimum phosphorus fixation for a soil was attained at from 80 to 90 percent base saturation.

Jenny and Ayers (20) investigating the influence of base saturation on the availability of potassium found that exchangeability of adsorbed potassium decreased with a reduction in the degree of saturation.

The possibility that percent of base saturation might also indirectly affect the growth of legumes such as sweet clover and alfalfa through its effect on nitrogen-fixing bacteria was indicated from data which Klingebiel and Brown (25) obtained. McCalla (27), working with soybeans, found that the best growth of the alfalfa and soybean bacteria was secured when colloidal clay was at least 50 percent saturated with calcium. No nodulation occurred when both the bacteria and the soybeans were grown in a medium containing no calcium.

EXPERIMENTAL PROCEDURE

Source of Material

Soil samples were obtained from 24 locations in central and northeastern Oklahoma, where experiments had been conducted to study the effect of lime and phosphate on the production of sweet clover. The period over which these experiments were conducted included the seasons of 1930-31, 1931-32, 1933-34, 1934-35, 1935-36, and 1941-42. The date and location of the experiments are given in Table I. During this period climatic conditions varied greatly. High temperatures and severe summer drought during the years of 1934 and 1936 were very unfavorable for plant growth. Rainfall varied in different localities during the other years, and yields were dependent to a great extent upon the available moisture supply. Fig. 1 shows the location of these experiments and the distribution of the average annual rainfall.

In the earlier experiments (1930-31) the limestone and phosphates were applied broadcast at rates from 3,000 to 6,000 pounds per acre, and from 200 to 500 pounds per acre, respectively, and then disked or harrowed into the surface soil. In later experiments (1932-42) the lime and phosphates were drilled in rows and the sweet clover seed dropped on the surface of the ground above the fertilized zone at time of planting.

The yield data for the sweet clover plots were secured from Oklahoma Agricultural Experiment Station Bulletins 206 and B248 and were tabulated for increase in yield of sweet clover from lime alone, from lime in lime-rock phosphate treatment, and from lime in lime-superphosphate treatment. These data are given in Table II. Data for the increase in yield from the use of lime alone were not available for all soils, therefore the lime-rock phosphate data were used in order to obtain a more uniform comparison.

TABLE I - DATE AND LOCATION OF THE SWEET CLOVER EXPERIMENTS STUDIED IN THIS INVESTIGATION

Soil No.	Date of Experiment	Location of Experiment
P8**	1930-31	F. J. Blecha, Perry, Okla.
P15	1930-31	C. J. Wallerstedt, Perry, Okla.
P36*	1930-31	Lincoln Co. Farm, Chandler, Okla.
P43	1930-31	V. W. Miracle, Okemah, Okla.
P64	1930-31	Roy Nichols, Checotah, Okla.
P69	1930-31	Cleve Martin, Mulhall, Okla.
P76	1930-31	W. O. Rittenhouse, Wagoner, Okla.
P83	1935-36	Frank Wilson, Okmulgee, Okla.
P206*	1930-31	L. A. Morton, Duncan, Okla.
P216	1930-31	Stanley Dugan, Pawnee, Okla.
P338**	1933-34	T. J. Swanda, Yukon, Okla.
P345	1933-34	Bob Stokes, Glencoe, Okla.
P352	1933-34	Vernon Cutler, Guthrie, Okla.
P359	1933-34	O. E. Correll, Stillwater, Okla.
P381	1930-31	Mrs. Mae Sumner, Vinita, Okla.
2790	1931-32	James Dobkins, Welch, Okla.
2797*	1931-32	A. A. Barnes, Pawnee, Okla.
4463	1935-36	J. E. Turner, Hallet, Okla.
4511*	1935-36	W. K. Blachly, Ramona, Okla.
4553*	1935-36	A. G. Hudspeth, Lexington, Okla.
4582	1933-34	E. R. Show, Stillwater, Okla.
4594	1931-32	N. W. Series 1700, Perkins, Okla.
4600	1934-35	John Oakleaf, Skedee, Okla.
9014	1941-42	Chilocco Indian School, Chilocco, Okla.

* Data not as significant because of soil variations and lack of sufficient replications.

** Yield limited by lack of moisture.

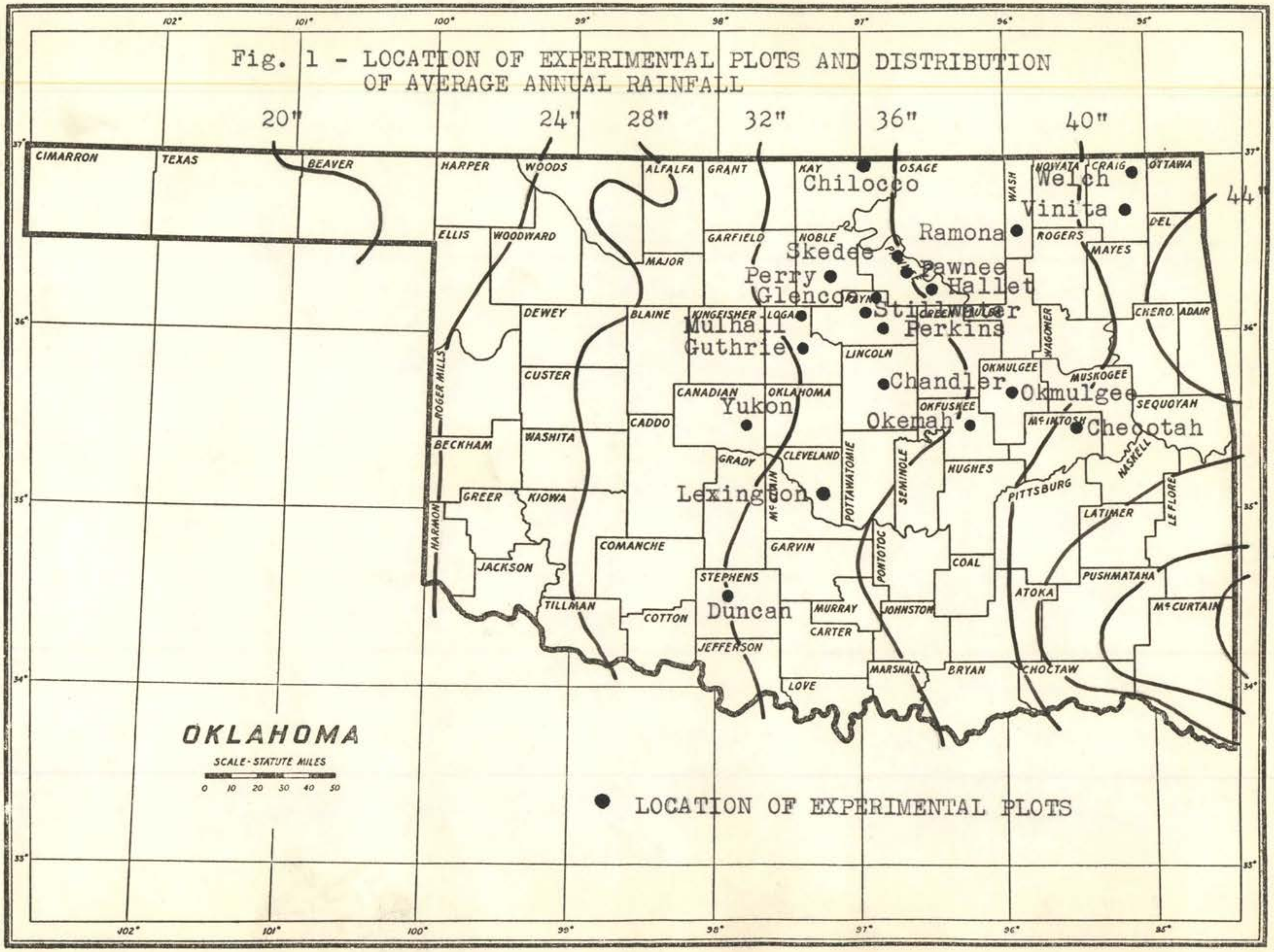


Fig. 1 - LOCATION OF EXPERIMENTAL PLOTS AND DISTRIBUTION OF AVERAGE ANNUAL RAINFALL

TABLE II - STUDIES ON THE EFFECT OF LIMESTONE WHEN APPLIED ALONE AND IN COMBINATION WITH ROCK PHOSPHATE AND SUPERPHOSPHATE ON THE YIELD OF SWEET CLOVER

Soil No.	Increase in Yield, Pounds per Acre: Lime over Check	Lime in Lime-Superphosphate	Lime in Lime-Rock Phosphate
P8	250	112	350
P15	1,710	230	150
P36	-146	650	715
P43	872	601	232
P64	593	2,442	3,147
P69	82	112	350
P76	837	1,367	939
P83*	---	1,350	755
P206	200	1,380	220
P216	683	3,080	3,780
P338*	---	530	2,450
P345*	---	1,970	1,200
P352*	---	790	2,350
P359*	---	1,530	1,615
P381	1,952	3,714	3,790
2790	1,663	850	2,380
2797	352	280	-690
4463*	---	320	880
4511*	---	425	-405
4553*	---	-35	-30
4582*	---	---	1,200
4594*	---	1,580	1,930
4600*	---	1,320	1,510
9014	5,872	3,925	---

* Small application of limestone, 100 to 400 pounds, drilled in row at time of seeding. On the other plots limestone was broadcast at the rate of 4,000 to 6,000 pounds per acre.

Methods of Soil Analysis

1. Determination of replaceable bases

Total replaceable bases were determined by official A. O. A. C. method (4).

2. Exchangeable calcium was determined by precipitation as oxalate in an acetic acid solution as recommended by Williams (39).

3. Exchangeable hydrogen was determined by a modification of the $Ca(OH)_2$ titration method (10).

Weigh out four ten gram samples of each soil and place in 25 x 150 mm. test tubes. Add various increments of 0.04 normal $Ca(OH)_2$ solution corresponding to 0.05, 0.1, 0.2, and 0.4 m.e. of calcium. The volume of lime water for the various concentrations will be 1.25, 2.5, 5.0, and 10.0 ml. Add water to make volume 20 ml., close with a cork stopper and shake vigorously. Place tubes in a water bath at 50°C and heat for one hour with occasional shaking. Remove from water bath, cool and determine the pH value of the soil suspension with a glass electrode. Plot the data in the form of a titration curve, using pH value on one axis and milliequivalents of hydrogen on the other. The milliequivalents of replaceable hydrogen were calculated at a pH of 7.0 in this investigation.

4. Mechanical analysis

The hydrometer method of Bouyoucos (6) was used to determine the percent of sand, silt, and clay in the soil samples.

5. Organic matter determinations were made using a modification of the wet combustion procedure by Schollenberger (37). Ten ml. of .4 N potassium dichromate solution was placed in a 200 ml. tall form Pyrex beaker containing one-half gram of 100-mesh soil. Fifteen ml. of concentrated sulfuric acid was added, the solution shaken vigorously and heated slowly on an asbestos pad to 165°C with frequent stirring. The solution was then cooled and diluted with 100 to 125 ml. of cold water and titrated with .2 N ferrous ammonium sulphate using orthophenanthroline as the indicator.

Procedures for the Determination of Base Saturation in Soil

Since the total exchange capacity of a soil is the sum of the total exchangeable bases and exchangeable hydrogen, the degree of base saturation may be calculated if any two of these three quantities are known. Any one of the following procedures may be used to determine the percentage of base saturation.

a. Determinations of total exchangeable bases and of exchangeable hydrogen (17)

b. Determination of total exchangeable bases of total exchange capacity (24)

c. Determinations of exchangeable hydrogen and total exchange capacity (32)

Because of the difficulty of determining the total exchange capacity Hissink (17) and other pioneer investigators used procedure (a). Kelley and Brown (24), however, have shown that Hissink's results are incorrect due to a fundamental error in the determination of the exchange capacity of the soil. In addition it was found that the determination of the total exchangeable bases may be subject to a considerable error because of the solution of non-exchangeable bases by the neutral salt used for leaching (22).

More recent work has resulted in a better understanding of the base exchange reaction of soils, and with this better understanding has come more accurate procedures. Among the best known of these have been the method developed by Kelley and Brown (22) for determining the total exchange capacity and the method of Parker (31) for determining exchangeable hydrogen. Pierre and Scarseth (32) modified Parker's barium acetate method of determining exchangeable hydrogen for the determination of the total exchange capacity. The modified method consisted of leaching soil with neutral, normal barium acetate and titrating the leachate electrometrically to determine exchangeable hydrogen. The soil was then leached with neutral, normal ammonium chloride to replace the barium by ammonium. The absorbed ammonium was then determined by distilling with magnesium oxide and titrating the distillate with 0.1 N sulfuric acid.

The method of Kelley and Brown (22) consisted of leaching the soil with neutral, normal ammonium chloride and determining the replaceable bases in the filtrate. Kelley (23) later substituted neutral, normal ammonium acetate for the chloride. The soil residue was then washed with ethanol and the total ammonia determined by distillation with MgO. Replaceable hydrogen was obtained by subtracting the replaceable bases from absorbed ammonium.

Schollenberger's ammonium acetate method (36) of determining both exchangeable hydrogen and total exchange capacity is of special interest because of its relative simplicity. Instead of leaching the soil with barium acetate, as in Parker's method, he leached the soil with ammonium acetate and titrated the leachings in order to determine the exchangeable hydrogen content. Since the exchange complex was believed to be saturated with ammonium by this treatment, he determined the amount of ammonium absorbed as a measure of the total exchange capacity.

The determination of base saturation by procedures (b) and (c) is objectional because of the lack of an accurate method for the determination of total exchange capacity. The methods previously mentioned depend upon the determination of the ammonium absorbed by a soil when treated with a neutral ammonium salt. Pierre and Scarseth (32) compared the barium hydroxide-ammonium chloride method of Kelley and Brown as slightly modified by Parker (31) with the barium acetate-ammonium chloride method and found that the latter procedure almost invariably gave lower values. Kelley and Brown (24) found that the ammonium chloride method gave low results with certain soils, and suggested that this is due, not so much to inaccuracies in the determination of the absorbed ammonium, as to the fact that the replacement of soil bases is incomplete. They also state that an error of more or less magnitude may be caused by the conversion of organic nitrogen compounds into NH_4 during the distillation process.

Procedure (a) was used in this study, total exchangeable bases being determined by the official A. O. A. C. method (4) and exchangeable hydrogen by $Ca(OH)_2$ titration, the milliequivalents of hydrogen being calculated at a pH of 7.0.

EXPERIMENTAL RESULTS

Base Saturation and Response of Sweet Clover to Lime

Data on the yield of sweet clover from unfertilized and limed plots were available for only thirteen of the twenty-four soils. Of the five soils with a base saturation above 80 percent only one showed an appreciable response to lime. Three of the soils (2797, P206, and P69) were 84 percent saturated with bases and showed average increases of 352 pounds, 200 pounds, and 82 pounds, respectively. A statistical analysis was not made of the original data to determine significant yields, but it is quite evident that the slight increases obtained would not be economical. Soil P36, with a base saturation percent value of 100 showed a decrease of 146 pounds per acre from liming as compared to the check plot. This was probably due to the decreased availability of phosphorus and other plant nutrients. Only one soil (P8) with a base saturation value of less than 80 percent failed to show an appreciable response to liming. The base saturation value for this soil was 77 percent and a partial explanation may be found in the fact that it was a silt loam containing 62.6 percent silt and drought was also a limiting factor in crop production on this plot.

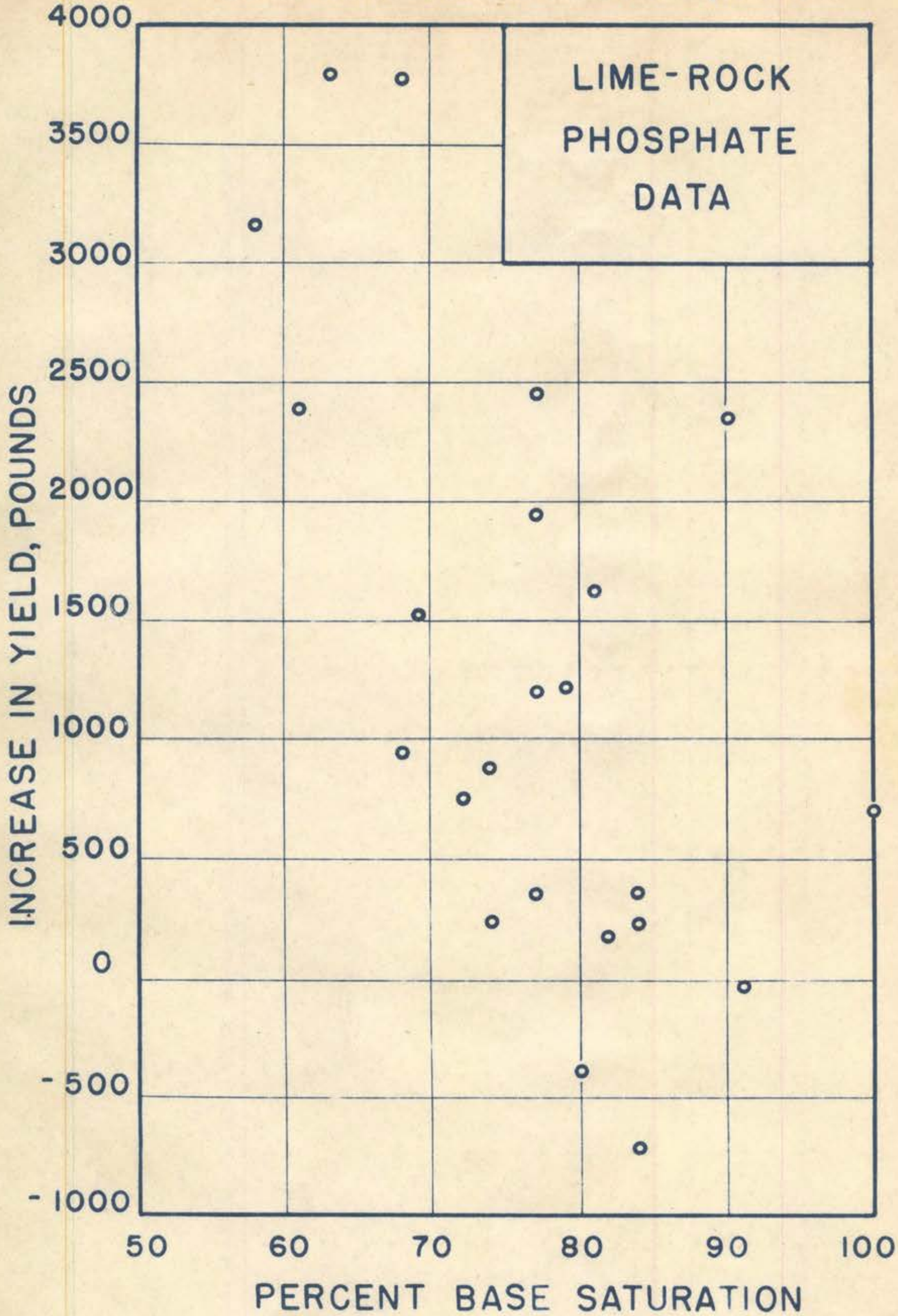
Yield data for lime-rock phosphate treatments over rock phosphate were available for twenty-three soils. These data, together with the results of chemical analyses of the soils and rate of liming, are given in Table III. As shown in Fig. 2 nine soils were more than 80 percent saturated with bases,

TABLE III - CHEMICAL ANALYSES OF EXPERIMENTAL SOILS, RATE OF LIMING, AND EFFECT ON SWEET CLOVER PRODUCTION

Soil No.	pH	Percent Organic Matter	Total Exchange Capacity[1]	Exchange-able Calcium[1]	Exchange-able Hydrogen[2]	Percent Base Sat-uration	Rate of Liming, Pounds/A	Increase in Yield, Pounds[3]
P8	6.0	1.57	10.6	5.3	2.4	77	4,500	350
P15	6.3	1.23	8.8	4.9	1.5	82	6,000	150
P36	7.6	0.60	4.6	2.8	0.0	100	6,000	715
P43	5.7	2.47	16.3	8.1	4.1	74	4,500	232
P64	6.1	1.50	6.2	2.7	2.6	58	6,000	3,147
P69	5.9	1.62	12.6	5.6	2.8	84	6,000	350
P76	5.7	2.79	11.4	6.1	3.6	68	4,500	939
P83	5.6	1.95	9.7	5.0	2.7	72	100	755
P206	6.9	0.92	9.3	5.0	1.5	84	4,500	220
P216	5.5	2.00	12.6	5.5	4.0	68	4,500	3,780
P338	5.8	1.50	8.7	4.5	2.0	77	400	2,450
P345	5.9	2.07	14.9	6.4	3.4	77	400	1,200
P352	5.5	1.57	9.9	5.5	1.7	90	100	2,350
P359	5.6	1.57	10.6	5.2	2.0	81	100	1,615
P381	5.3	1.84	7.0	3.3	2.6	63	4,500	3,790
2790	5.2	2.52	11.8	5.0	4.5	61	4,500	2,380
2797	5.9	1.84	15.1	8.7	2.4	84	4,500	-690
4463	5.7	1.98	13.0	6.5	3.3	74	100	880
4511	6.3	3.12	16.8	10.4	3.3	80	100	-405
4553	6.2	0.78	7.0	3.7	0.6	91	100	-30
4582	6.1	1.26	10.7	5.8	2.2	79	100	1,200
4594	5.5	1.17	6.9	4.0	1.6	77	400	1,930
4600	6.1	1.53	7.7	3.7	2.4	69	100	1,510
9014	5.6	2.81	14.5	7.9	3.4	76	4,000	3,925*

[1] m.e. per 100 g. of soil
[2] m.e. per 100 g. of soil at pH 7.0
[3] Lime-rock phosphate data
* Lime-superphosphate data

Figure 2 - A comparison of base saturation in 23 surface soils and the effect of lime on sweet clover production.



and of these nine only three showed an appreciable response to lime. Two of these soils, P352 and P359, had a pH of 5.5 and 5.6, respectively, although P352 was 90 percent saturated and P359 was 81 percent saturated. The organic matter content of these two soils was the same, 1.57 percent; this value is much greater than that of soils of similar degrees of base saturation.

The reason for the increase in yield for soil P36 is apparently the joint effect of lime and phosphate, as the lime-alone data shows a decrease in yield.

There is a marked depressing effect produced by lime on soils 4511 and 2797 which are 80 and 84 percent, respectively, saturated with bases.

Data from lime-superphosphate treated soils were available for twenty-three of the twenty-four soils. Five of nine soils over 80 percent saturated with bases show a noticeable response to liming. Two of that group, P206 and P36, do not show an appreciable response to lime-alone, so apparently the increase is due to the mutual effect of lime and phosphate.

A third soil, 2797, shows an increased yield from lime-superphosphate treatment, but a marked decrease in yield from lime-rock phosphate treatment. This difference may be attributed to the effect of the more readily available phosphorus from the superphosphate in an alkaline medium.

Only two of the fifteen soils having a base saturation value below 80 percent fail to show a response to lime. These soils, P8 and 4463, were 77 and 74 percent, respectively, saturated with bases.

Effect of Soil Texture and Response to Liming

It was thought that a better understanding of the problem would be afforded by studying the response of sweet clover to lime and its relationship to soil texture. Accordingly, the twenty-four soils were grouped into classes using the method of Bouyoucos (6) for mechanical analysis. These data are given in Table IV.

The yield data obtained from the lime and rock phosphate treatments were used in preparing the graphs for the various textural groups. The lime-superphosphate yield data are very similar to the lime-rock phosphate data with the exception that the superphosphate data show a slightly greater response for most soils.

Sandy Loam: Three of the five soils in this group are over 80 percent saturated with bases. Fig. 3 shows that only one soil over 80 percent saturated responded appreciably to liming; this soil, P36, showed no response to lime-alone, but instead a marked decrease. The response shown in this figure is no doubt due to the mutual effect of the lime and phosphorus. These data indicate that a decrease in response of sweet clover to liming may be expected when the base saturation value is 80 percent or higher.

Loam: There were only two soils in this class, and although one is 91 percent saturated with bases and the other 79 percent saturated, both show rather large responses to liming in the lime-rock phosphate data. This suggests that similar soils of this texture group will require a higher

TABLE IV - MECHANICAL ANALYSIS DATA FOR EXPERIMENTAL SOILS

Sample No.	Percent Sand and/or Coarse Material	Percent Clay	Percent Silt	Texture Group
P8	18.2	19.2	62.6	Silt loam
P15	23.3	24.8	51.9	Silty clay loam
P36	68.2	10.8	21.0	Sandy loam
P43	20.5	18.6	60.9	Silt loam
P64	53.3	12.6	34.1	Sandy loam
P69	40.3	25.8	66.1	Silty clay loam
P76	24.7	22.8	52.5	Silty clay loam
P83	29.7	14.0	56.3	Silt loam
P206	60.2	17.6	22.2	Sandy loam
P216	25.5	28.0	26.5	Clay loam
P338	30.2	18.0	51.8	Silt loam
P345	30.0	29.4	40.6	Clay loam
P352	42.0	19.2	38.8	Loam
P359	49.0	26.8	24.2	Clay loam
P381	22.2	16.0	61.8	Silt loam
2790	19.2	25.9	54.9	Silty clay loam
2797	25.3	28.8	45.9	Clay loam
4463	39.7	27.4	32.9	Clay loam
4511	31.7	27.4	40.9	Clay loam
4553	52.9	17.7	29.4	Sandy loam
4582	45.7	19.3	35.0	Loam
4594	51.0	11.6	37.4	Sandy loam
4600	41.2	17.3	58.5	Silt loam
9014	15.2	26.0	58.8	Silty clay loam

degree of base saturation for optimum growth of acid-sensitive crops.

Silt Loam: The six soils in this texture group are all less than 80 percent saturated with bases. Fig. 4 shows that one soil (P43) does not give an appreciable response to lime at 74 percent saturation with an exchangeable calcium content of 8.1 m.e. per 100 g. of soil. The lime-superphosphate data show that soil P8 at 77 percent saturation also fails to show a noticeable response. It appears that a base saturation value of 75 percent is the maximum value at which an appreciable response may be expected from sweet clover to liming for this textural group.

Silty Clay Loam: Data from four of the five soils in this group are shown in Fig. 5. Two of the soils in this group are over 80 percent saturated; one of these soils shows an appreciable response. The maximum base saturation value for an appreciable response of sweet clover to lime is also approximately 75 percent for this group.

Clay Loam: Three of the six soils in this group are over 80 percent saturated with bases. Limestone increased the yield of sweet clover on only one of them as indicated in Fig. 6. The other two soils over 80 percent saturated show marked decreases in yields from liming, the decreases being -405 and -680 pounds.

Figure 3 - A comparison of base saturation in 5 sandy loam soils and the effect of lime on sweet clover production.

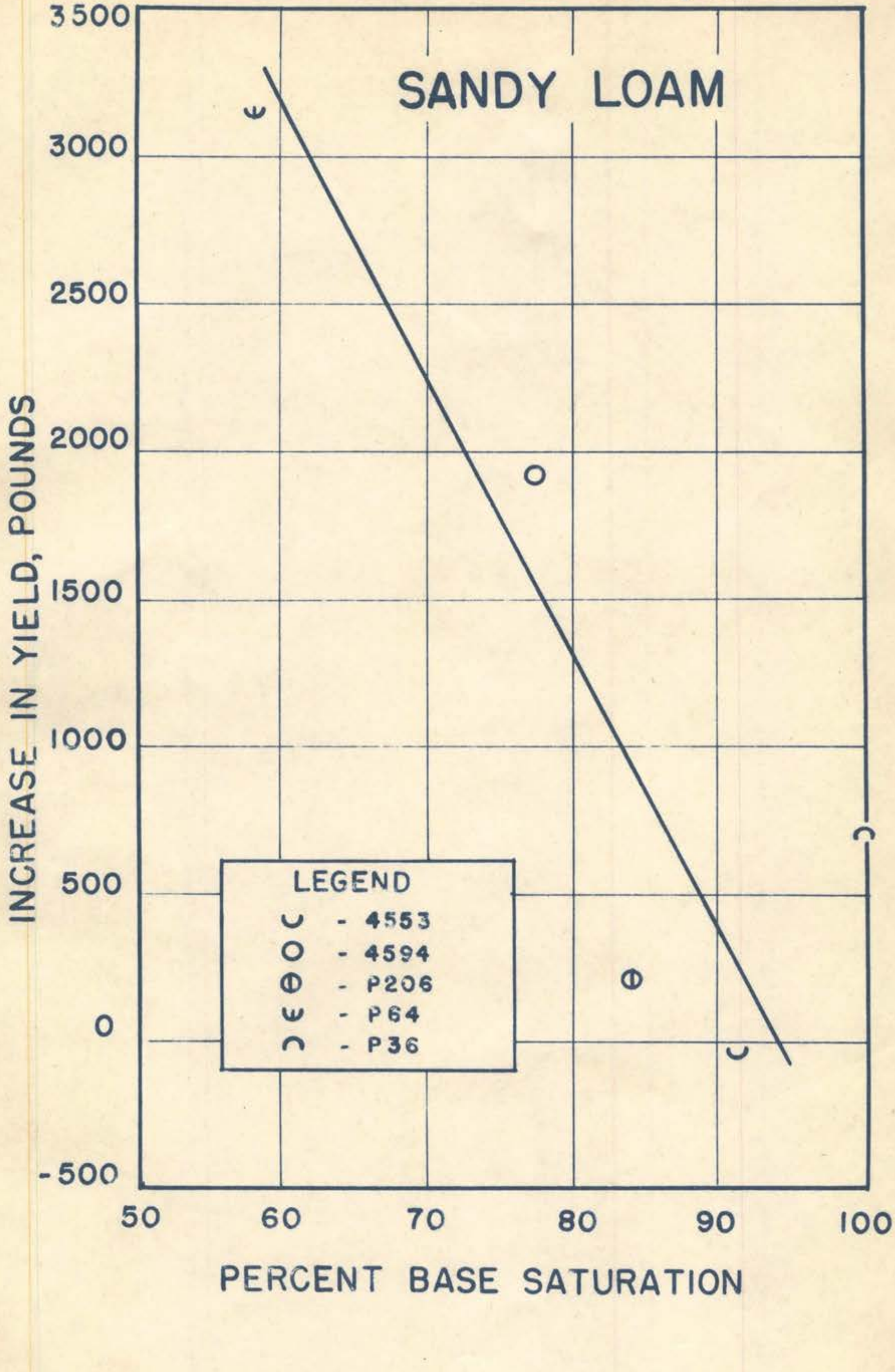


Figure 4 - A comparison of base saturation in 6 silt loam soils and the effect of lime on sweet clover production.

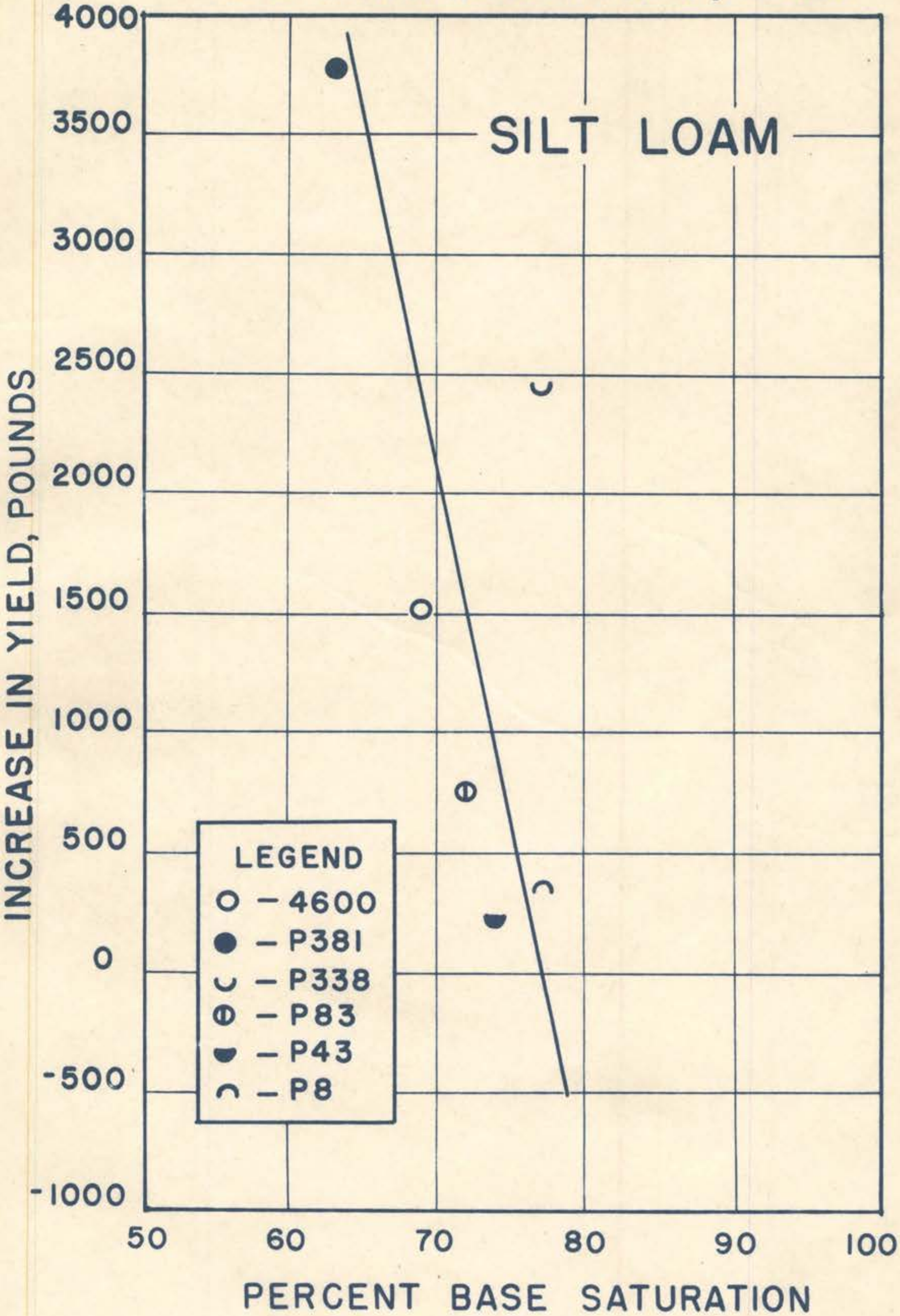


Figure 5 - A comparison of base saturation in 4 silty clay loam soils and the effect of lime on sweet clover production.

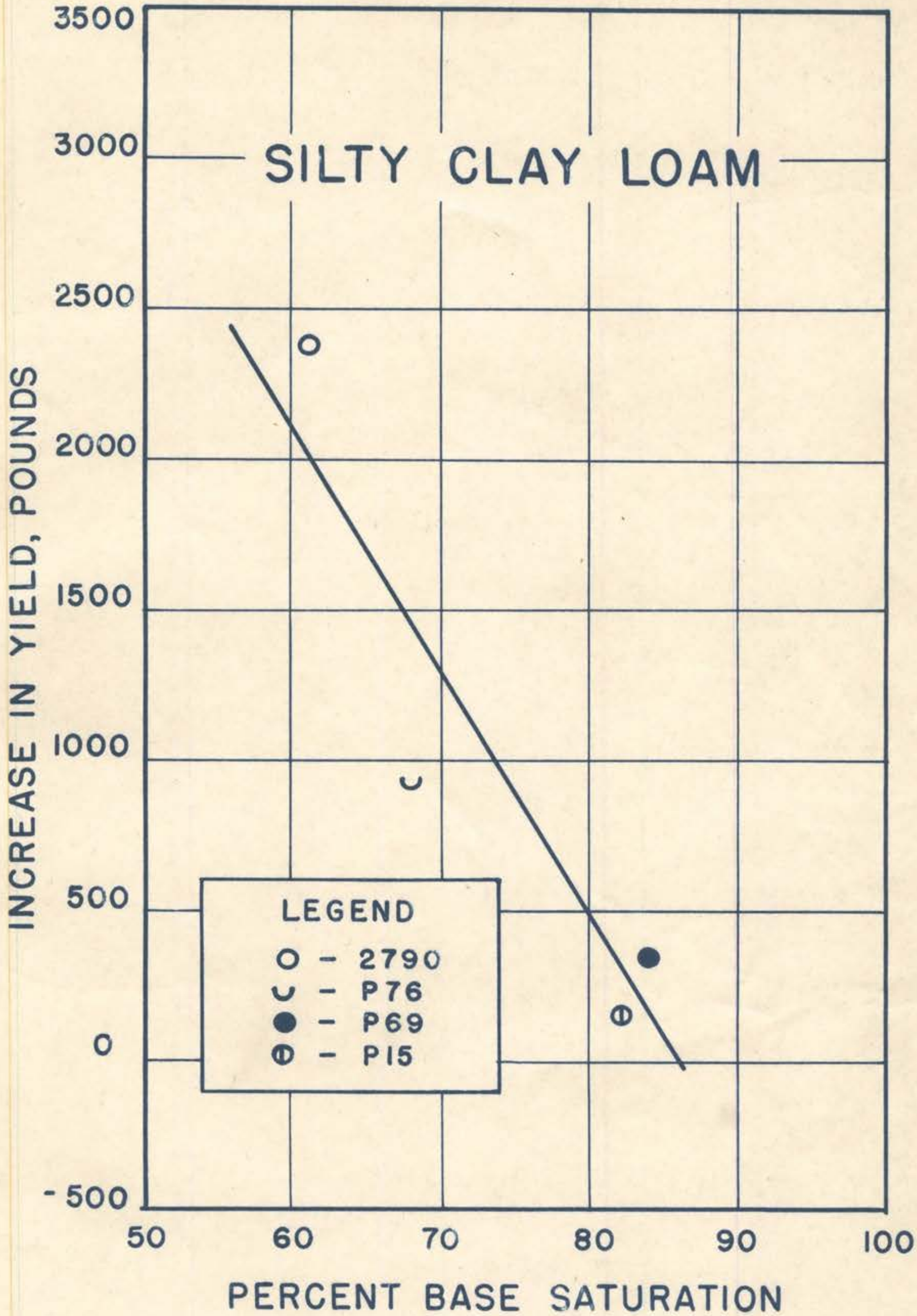
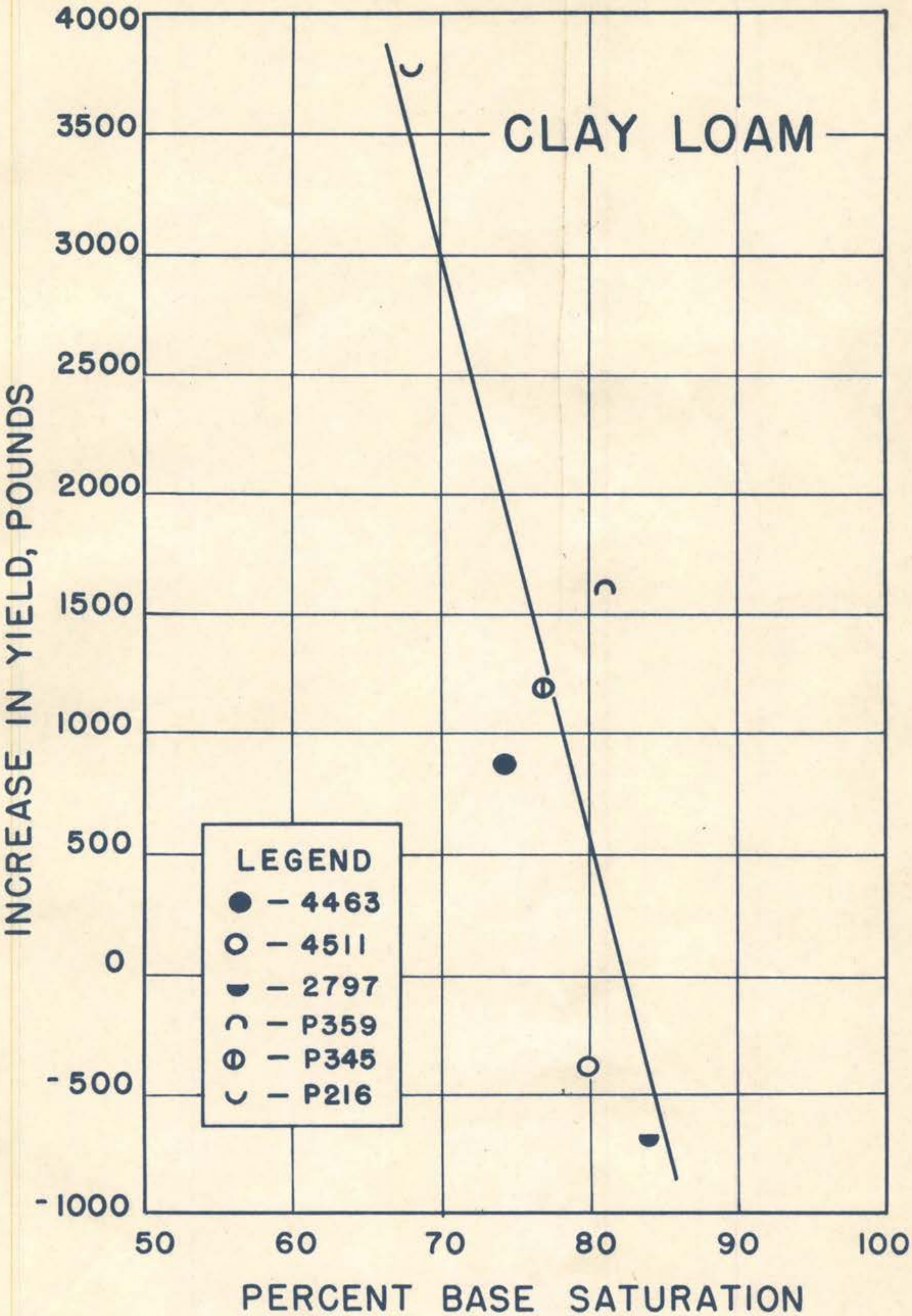


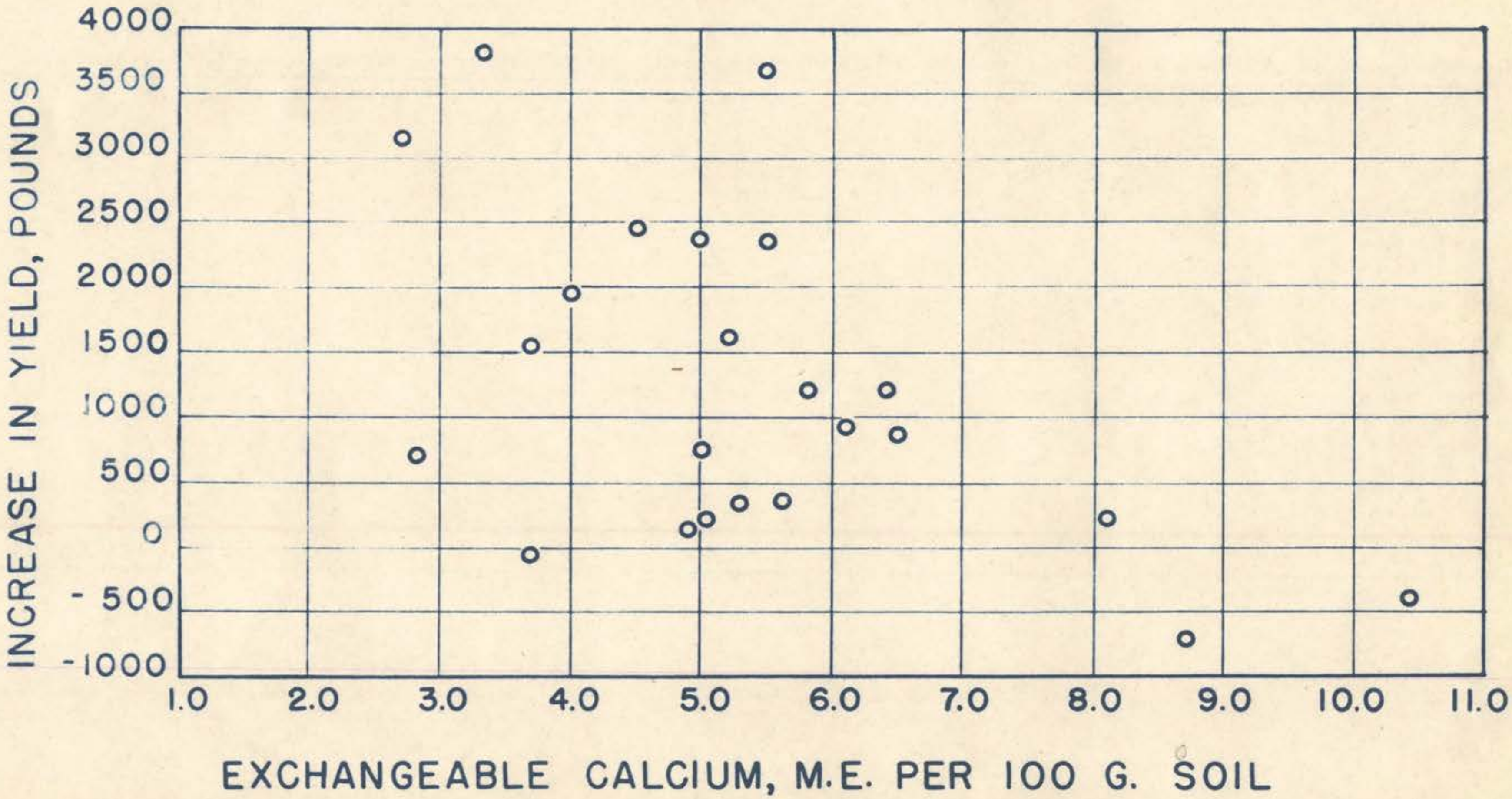
Figure 6 - A comparison of base saturation in 6 clay loam soils and the effect of lime on sweet clover production.



Exchangeable Calcium and Response to Lime

In this study no close relationship was found to exist between the response to lime as shown by the increased yield of sweet clover and the amount of exchangeable calcium. Fig. 7 shows a general decrease in response with increasing amount of exchangeable calcium, with no appreciable increase in yield when the exchangeable calcium content is more than 8.0 m.e. per 100 g. of soil. These data suggest that the neutralizing action of the lime is more important than the exchangeable calcium thus furnished. For instance, soils P64 and P36 contain 2.7 and 2.8 m.e. of exchangeable calcium, respectively, yet P64, with a pH of 6.1, shows an increase in yield of 3,147 pounds from the application of lime while P36, with a pH of 7.6, shows an increase of 715 pounds. The organic matter content of P36 is only 0.6 percent while that of P64 is 1.50 percent.

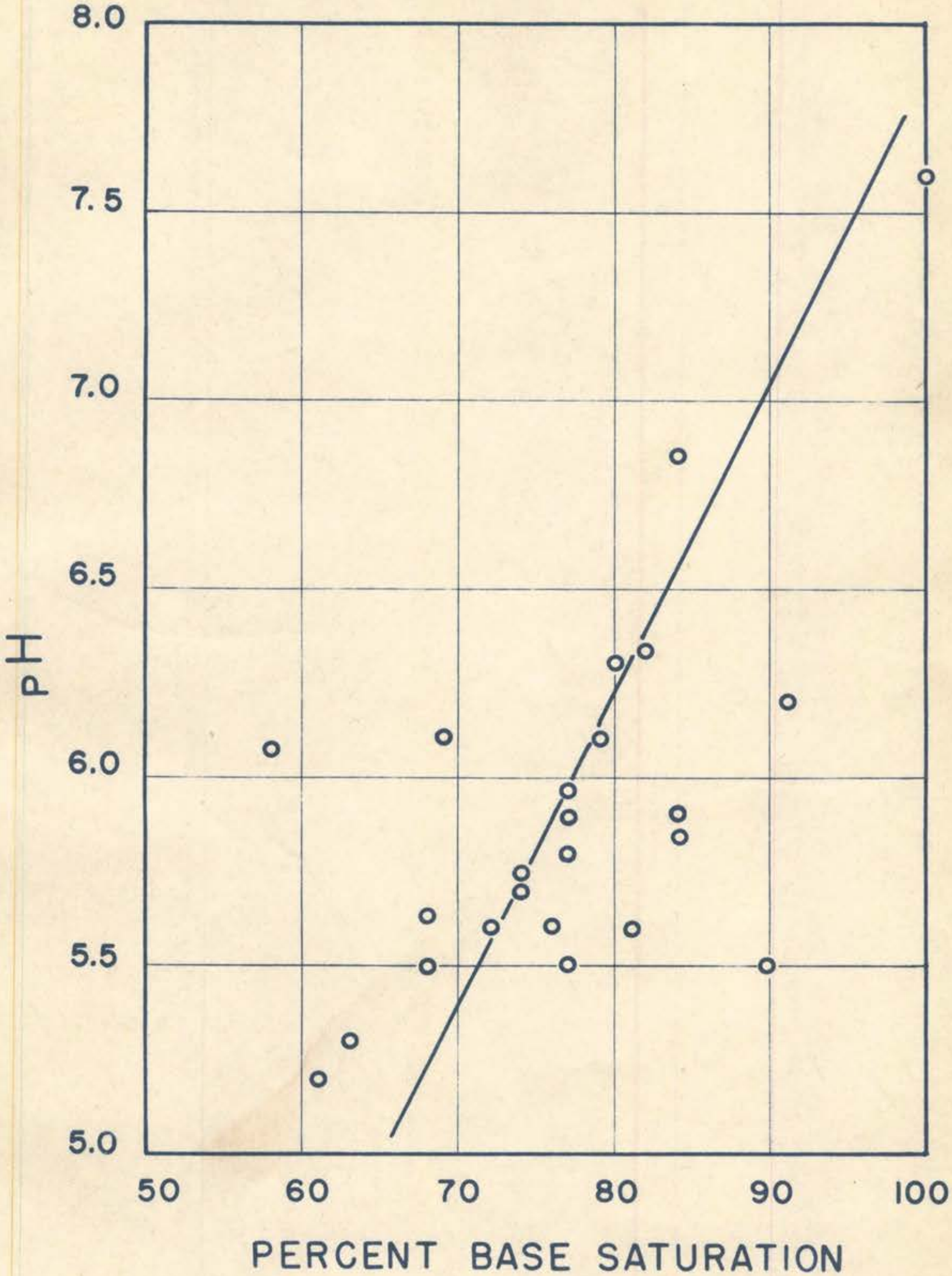
Figure 7 - A comparison of exchangeable calcium in 23 surface soils and the effect of lime on sweet clover production.



Chemical Studies

Many soil tests are dependent upon methods for determining pH value. If a close relationship should exist between pH and degree of base saturation, this relationship could be used as a basis for making recommendations for limestone applications on soils on which sweet clover is to be grown. These data for this study were plotted and are shown in Fig. 8. It is evident from this graph that a fair correlation between pH and base saturation exists for the soils in this study. The plotted line of regression was determined by the method of least squares and the correlation coefficient was found to be .61. There are four soils which depart rather strikingly from the line and in seeking a possible explanation for this departure, analyses were made to determine the organic matter content of the soils studied in this investigation. These and other chemical data are given in Table III. No close relationship between the pH value and organic matter content was found. A general relationship was found between organic matter content and base saturation in which the two values varied inversely. These soils which departed from the plotted line of regression, P64, 4600, P352, and 4553, all contain less than 1.60 percent organic matter. For P64 and 4600 this quantity is relatively low when compared to soils of similar percent base saturation values. The organic matter content of P352 is 1.57 percent, which is relatively high when compared to soils of the same range of degree of base saturation (P206, 0.92 percent; P36, 0.60 percent). The organic matter

Figure 8 - Relation of pH value and degree of base saturation of the base exchange complex in 24 samples of surface soil.



content of 4553, 0.78 percent, apparently is not the reason for its departure from the line, as the value is near that of soils of a similar degree of saturation.

Several investigators have studied the relationship between pH and degree of base saturation of soils. Conrey and Schollenberger (8) obtained a fair correlation between these two values of the various horizons in a Clermont soil profile. Green (11), Bray and DeTurk (7), Walker and Brown (38), and Merkle (26) all found a rather close relationship between the pH and degree of base saturation of soils. Joffe and McLean (21), however, concluded that there is no correlation between the hydrogen-ion concentration and degree of base saturation. Pierre (33) also observed that the hydrogen-ion concentration of soils and the degree of saturation of the exchange complex with bases were not correlated in soils that varied widely both in physical and chemical characteristics and suggested that the rather close relationship between these two characteristics obtained by other investigators may be due to the fact that they had worked with soils of similar origin or of similar physical and chemical characteristics.

Pierre and Scarseth (32) and other workers (21, 8) found that soils of the same pH values may have very different degrees of saturation. They suggest that the following factors should be considered in explaining the fact that soils differ greatly in their percentage base saturation at given pH values.

1. Presence of soluble acids
2. Nature of the bases in the exchange complex

3. Nature of the exchange complex as might be revealed by
    a. Organic matter content of the soil
    b. Silica-sesquioxide ratio of the soil colloid
    c. Total exchange capacity of soil colloid
4. Strength or avidity of the soil acids

Since all the soils in this study developed under a subhumid, temperate climate the clay minerals will be similar in composition; however, some variation in organic matter occurs which apparently is an important factor in explaining the departure of several of the soils from the general relationship which was found to exist between pH and degree of base saturation.

There was a general relationship between the percent clay and the total exchange capacity of the soils, the total exchange capacity increasing directly with the clay content.

Discussion

Until recently (29) it was thought that soil acidity had to be completely neutralized to provide optimum conditions for the growth of acid-sensitive crops. Several workers (25, 3, 12, 28) have found that small applications of limestone applied in the drill row produce practically the same increases in yields as much larger applications applied broadcast. Similar results were obtained by Harper (15) in the second group of experiments from which data for this study were secured. The experimental plot on the John Oakleaf farm, near Skedee, Oklahoma, showed an increase of 1,510 pounds of sweet clover when limestone was applied in the drill row at the rate of 100 pounds per acre. Applying lime and fertilizers in the row with the sweet clover seed at the time of planting will provide the young plants with a readily available supply of calcium and other plant nutrients during the seedling stage of development. This treatment will keep the plants alive until they have developed a root system capable of securing nutrients if they are available from the surface and sub-surface soil. If the sub-surface soil is sufficiently acid, or is low in phosphorus, the growth of the plants may be inhibited by a nutrient deficiency when the roots develop outside the limed and fertilized zone.

When limestone is applied broadcast at the rate of one or two tons per acre and thoroughly mixed with the surface 6-inch layer of soil, the concentration of calcium at any particular point in the soil is necessarily low. The limestone between the plants or rows of plants cannot be utilized unless the plant roots come in contact with the limestone particles, and consequently a considerable amount of the calcium will not be used. Finely ground limestone applied in the row over an area 2 inches wide and 3 inches deep at the rate of 100 pounds per acre would be equivalent to an application of 4,000 pounds per acre broadcast and mixed with the surface 6-inch layer of soil. Row application of limestone provides a small, well-saturated zone in the immediate vicinity of the plant roots and provides more efficient utilization of the calcium thus applied. The poor results from row fertilization in some instances may have been due to an insufficient quantity of finely divided limestone to saturate the base-exchange complex in the fertilized zone. If the subsoil were acid and plants would be required to obtain a higher percentage of their calcium from the limestone applied it would be insufficient in some soils unless the rate of application were increased. Because of the small amount of limestone usually added in row applications and its efficient utilization by sweet clover plants, lime must be applied whenever a succeeding crop of sweet clover is planted.

Although calcium saturation in the surface soil is undoubtedly a primary factor in the growth of the sweet clover seedling, the chemical character of the sub-surface layers may be a very important factor in subsequent development. Small applications of lime applied in the drill row are more effective in increasing the growth of sweet clover on acid soils which have a neutral or basic subsoil than on soils having a deeply leached profile.

Summary

A study was made of the relation between response of sweet clover to liming and base saturation of the soil. No appreciable response of sweet clover to liming should be expected on soils that have a base saturation value of 80 percent or more. This may be somewhat modified by the application of phosphate fertilizers.

The data for the various soil classes show that sandy loams, silty clay loams, and clay loams do not respond to liming when the base saturation value is above 80 percent. Silt loams show no response when the base saturation value is above 75 percent. The data for the two loams in this study indicate that some response may be secured from liming sweet clover on such soils when the degree of base saturation is as high as 90 percent.

A fair correlation between pH and the percent of base saturation of soils was observed in this study. A pH of 6.2 approximates a base saturation value of 80 percent.

A general correlation between the percent of clay and the milliequivalents of exchangeable calcium per 100 g. of soil exists for the soils studied. Exchangeable calcium increased with increasing clay content. A direct relationship was also found between percent clay and the total exchange capacity.

There was no close relationship between the response of sweet clover to liming and the amount of exchangeable calcium.

The organic matter content of a high percentage of the soils studied varied inversely with the percentage of base saturation.

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