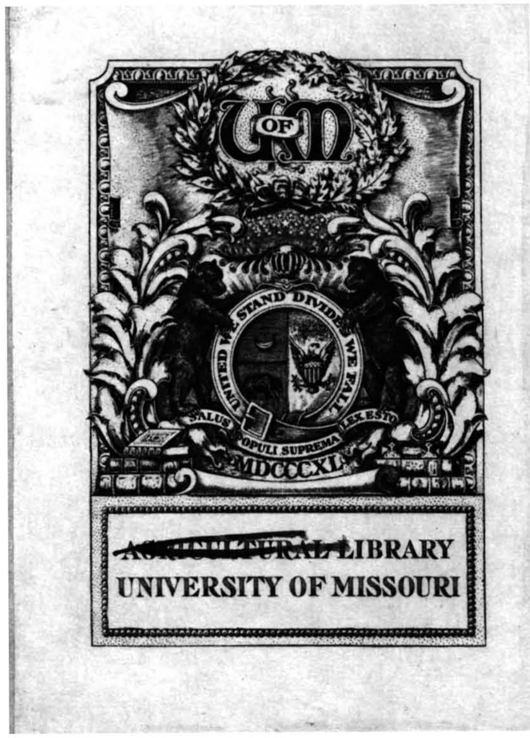
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A STUDY OF THE EFFECT OF LIMING AN ACID SOIL ON THE GROWTH OF CERTAIN LEGUMES AND NON-LEGUMES

by

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SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in the

GRADUATE SCHOOL

of the

UNIVERSITY OF MISSOURI

1914

BIBLIOGRAPHY

1. Wallerius, Johan Gotschalk, Agriculturae Fundamenta Chemica: Akerbrukets Chemiska Grunder, 1761, Upsala.

2. Davy, Humphrey, Elements of Agricultural Chemistry, London, 1813.

3. H. J. Wheeler, Rhode Island Bulletin 46, Rhode Island Experiment Station Report 1895, 1898, Journal of Industrial and Engineering Chemistry, 1910.

4. H. J. Wheeler, G. E. Adams, Rhode Island Bulletin 96.

5. Kellerman, Bureau of Plant Industry Bulletin 100.

6. M. Nagaoki, Bulletin College of Agriculture, Tokyo Imperial University, 6, 1904, No. 3, pp. 194-214.

7. S. Suzuki, Bulletin College of Agriculture, Tokyo Imperial University, 6, 1905, No. 4, pp. 347-351.

8. D. Pryanesknikov, Jour. Exp. Landw. 4, 1903, No. 3, pp. 257-266.

9. P. S. Kossovitch and L. Althausen, Russ. Jour. Exp. Landw. 10 (1909), No. 5, pp. 693-695.

10. F. D. Gardner, B. E. Brown, Penn. Sta. Rept. 1911, pp. 60-76.

11. F. Westhausser, W. Zielstorf, Landw. Vers. Stat, 65 (1907) Nos. 5-6, pp. 441-447.

12. A. Otryzanev, Russ. Jour. Exp. Landw. 8 (1907), No. 2, pp. 204-206.

13. B. Schulze, Jahresber. That. Agr. Chem. Vers. Stat.

Provinz Schleisen, 1901-1902, pp. 21-32.

14. B. Schulze, Fühling's Landw. Ztg. 53 (1904) No. 5, pp. 186-188; No. 6, pp. 216-222; No. 7, pp. 261-262.

15. Bachman, Fühling's Landw. Ztg. 52 (1903), No. 1, pp. 12-14.

16. C. A. Mooers, Tenn. Sta. Bul. 9, pp, 57-90.

17. C. A. Mooers, Tenn. Sta. Bul. 90.

18. W. B. Ellett and H. H. Hill, Rept. Va. Polytech. Inst. 1909-1910.

19. J. W. Patterson and R. R. Scott, Jour. Dept. Agr. Victoria 10, 1902.

20. W. F. Sutherst, Chemical News, 85 (1902), No. 2210, p. 157.

21. J. E. Greaves, Jour. Biol. Chem. 7 (1910, No. 4, pp. 287-319.

22. E. W. Gaither, Jour. Indus. and Eng. Chem., 2 (1910) 67, p. 315.

23. F. B. Guthrie and L. Cohen, Agr. Gaz. N. S. Wales 18 (1907), No. 12, pp. 952-956.

24. E. Rousseaux and C. Breaux, Ann. Sci. Agron., 3 Ser. 3 (1908), II No. 3, pp. 370-396.

25. H. J. Wheeler, Jour. Indus. and Eng. Chem., 1910, p. 135.

26. Hartwell and Kellogg, Rhode Island Exp. Sta. Rept., 1903, p. 253.

27. Burt L. Hartwell, R. I. Sta. Bul. 154.

28. Phillipp Schneider, Jour. für Landw. 52, p. 97.

29. J. G. Lipman, Bacteria in Relation to Country Life, p. 44.

30. C. G. Hopkins, Soil Fertility and Permanent Agriculture, p. 163.
31. P. E. Brown, Iowa Research Bulletin No. 2.
32. D. Engberding, Centralb. für Bact. 2 Abt. 23 (1909), No. 21, pp. 21-25, pp. 569-642.
33. W. A. Withers and G. S. Fraps, Jour. Amer. Chem. Soc. 24 (1902) No. 6, pp. 528-534.
34. T. L. Lyon and J. A. Bezzell, Jour. Indus. and Eng. Chem. 2 (1910), No. 7, pp. 313-315.
35. W. Krüger, Bot. Centbl. 114 (1910), No. 9, pp. 238-239.
36. J. G. Lipman and P. E. Brown, New Jersey Sta. Rept. 1907, pp. 141-204.
37. S. S. Peck, Hawaii Sugar Planters Sta. Agr. and Chem. Bul. 37, pp. 5-38.
38. H. Fisher et al. Landw. Jahrb. 4(1911), No. 5, pp. 755-822.
39. J. W. Patterson and R. R. Scott, Jour. Dept. Agr. Victoria 10 (1912), No. 7, pp. 393-400.
40. Voorhees, Lipman and Brown, N. J. Bul. 210.
41. Vogel, Illus. Landw. Ztg. 28 (1908), No. 21, p. 185.
42. Wohltman and Bergene, Jour. Landw. 50 (1902), No. 4, pp. 377-395.
43. A. V. Donnan, Agr. Gaz. N. S. Wales 23 (1912), No. 11, p. 956.
44. P. Q. Keegan, Nature, Vol. 66, No. 1722, p. 655.
45. E. Kroeber, Jour. für Landw. 57-9.

INTRODUCTION

A number of investigators have found that applications of lime to an acid soil have in many cases resulted in a depression of crop yields. This effect has been observed especially in connection with pot cultures where various phosphate fertilizers have been used and where the applications of lime have been heavy or applied immediately before the growth of plants.

P. E. Karraker at this Station observed a depressing effect of ground limestone on the growth of certain legumes. It was purposed in the experiments herein reported to continue the work begun by Karraker in order to determine whether the effects observed on the first year's growth would continue during the second year. It was also planned to add other experiments with the hope of obtaining information which might give some indications of the cause of the depressing effects observed. In addition to this, it was intended to make further observations on the effect of ground limestone on the growth of certain legumes and cereals and on the action of certain bacteria in the soil, namely, tubercle bacteria and nitrifying organisms.

The application of lime to the soil is one of the oldest agricultural practices. The ancient Roman writer, Pliny, mentions in his writings the fact that the most progressive Roman farmers practiced marling more than two thousand

years ago. In English agriculture the use of lime, marl, oystershell, etc., had already become quite an extensive practice at the beginning of the era of modern agriculture two or three centuries ago. The English have applied chalk, ground shells and other calcareous materials in large quantities to sour, marshy lands for the purpose of sweetening the soil. In America liming has become most extensive in the older settled regions of the eastern states where limestone and abundant timber have made it possible to erect lime kilns and produce burnt lime. The use of lime as a soil amendment, therefore, is a very old practice which has grown out of the beneficial results observed in the experience of farmers through centuries past.

Only within recent years, however, have experiments been made explaining the action of lime on the soil. In the latter half of the eighteenth century scientists devoted considerable time in search of plant nutrients. Calcium was found to be one of the essential elements; and the early idea regarding the benefit of lime was that it supplied a necessary plant food which was lacking in the soil. But beneficial results were obtained on soils containing an abundance of calcium to supply the nutritive needs of plants for that element; and, moreover, the benefits from liming were often far in excess of what could be possible merely from its supplying any deficiency of calcium for plant food purposes. Other factors, therefore, were responsible for its beneficial influence; and lime was classed as an indirect manure, the action of which was due to factors not concerned with supplying the plant with

calcium. As early as 1761 Wallerius[1], professor of chemistry at Upsala, expressed the idea that certain constituents of the soil were nutrients while others were only instrumental in making the proper food mixture. Thus, chalk and probably salts help in dissolving the fatness of the humus. And later Humphrey Davy[2] stated that lime is useful because it dissolves hard vegetable matter. Modern investigators explain the effect of lime as being due to one or more of several influences which it has in the soil. These influences are classified as physical, chemical, physiological and bacteriological.

The physical effect of lime depends upon the nature of the soil to which it is applied. It is a flocculating agent and has the effect of making clay soils more porous and friable, thereby increasing aeration, facilitating the movement of capillary water, and improving the structure to some extent. On light sandy soils it decreases the porosity by cementing the soil particles together. This increases the water holding power of the soil and limits aeration to some extent, making a more favorable medium for the growth of bacteria. While the physical effects may be of minor importance in themselves, their indirect influence in affecting chemical changes and bacterial growth in the soil may be far reaching.

The chemical action of lime is the effect usually first considered. Its power to sweeten sour soils by neutralizing the acid condition is well known. It is for this purpose that practically all applications of lime are made. But, as modern investigators have found, this is only one of the

chemical influences of lime. When lime is mixed with the soil, various chemical reactions take place which liberate or make less soluble many of the soil constituents, some of which are important elements of plant food. Lime has come to be regarded, therefore, not only as a corrector of soil acidity but also as an indirect fertilizer. It is mainly in relation to potassium and phosphorus that reactions of importance to plant growth take place. Its action in liberating potash has been noted by many investigators. Its effect upon phosphorus as stated in some accounts seems to depend upon the condition of the phosphorus in the soil. It has been stated that where it exists as iron or aluminum compounds, lime reacts with them, forming calcium phosphate which seems more available to plants. Its effect upon calcium phosphate, however, is said to be to retard the changes of phosphorus to more soluble forms. Some of the most important chemical effects of lime come about indirectly through the action of bacteria. For example, the hastening of the decay of organic matter and increased production of carbon-dioxide is only one of the chemical influences which lime produces indirectly through its bacterial influence.

By some investigators the physiological effects of lime upon the growth of plants has been emphasized. According to Loew, the ratio of calcium and magnesium which may be absorbed by plants seems to affect their growth materially, hence the addition of lime to the soil which would alter the existing ratio between those two elements would affect the the plants in a commensurable degree. The reaction of the

soil, whether acid, alkaline or neutral has an important influence upon plant growth, different plants being affected differently and to different degrees by the acidity or alkalinity of the soil. Applications of lime which neutralize the acidity and furnish more basic material may change the nature of vegetation by producing more favorable conditions for some plants and less or relatively less favorable conditions for others.

The study of soil bacteria has shown that the bacteriological effects of liming are among its most important influences. Bacteria are very sensitive to any changes in the medium in which they grow; and practically all bacteria of great importance in the soil are harmfully affected by acid conditions. The basic material, therefore, which is furnished by lime to neutralize the acids already present or which develop may entirely alter the bacterial flora of the soil. The organisms of decay are all favored by the presence of lime. As was already mentioned, lime, by its influence upon the bacteria, hastens the decay of organic matter and the production of carbon dioxide, which, in the form of carbonic acid, is instrumental in making plant food available. The decomposition of proteid material is also favored; and ammonification is increased. The presence of calcium to neutralize the nitric acid produced by the nitrifying organisms makes possible the continuation of the process and the accumulation of nitrates in the soil. The nitrogen fixing organisms, whether symbiotic or non-symbiotic, are dependent upon lime. The azoto-

bacter cannot flourishunder acid conditions; and the bacteria of legumes refuse to develop in a strongly acid soil. The inoculation of most legumes is hardly possible in a very acid soil. The fixation of free nitrogen from the air, therefore, is quite dependent upon a sufficient supply of lime.

Such in brief are the current explanations of the effect of lime in the soil.

A REVIEW OF THE RESULTS OF THE MORE IMPORTANT INVESTIGATIONS CONCERNING THE EFFECTS OF LIMING

THE EFFECT OF LIME ON GROWTH

Lime is applied with the expectation that it will prove a benefit to the crops growing on the soil thereafter; and crops are usually benefitted by its action, but not always. Notwithstanding the great number of instances which might be cited to show where lime has benefitted plant growth, injurious effects have not infrequently been noted. Perhaps the most extensive work which has been done to observe the effects of liming on the growth of various plants under natural field conditions has been done by Wheeler[3] of the Rhode Island Experiment Station. The soil on which the experiments were conducted was very acid. Air slaked lime was applied at the rate of 5400 pounds per acre in the spring of 1893 and again at the rate of 1000 pounds per acre in the spring of 1894. During the next four years Wheeler observed the effect on a large number of plants, including nearly all the common cereals, grasses, legumes and garden vegetables. Most of the crops were benefitted, in some cases being increased seventy-seven fold. Some, however, were injured; and strangely among those injured are found some of the common legumes. The list of plants whose growth was reduced by liming includes, among others, cowpeas, millet, beans, watermelons, blue lupines, seradella and in

some years rye and corn. In some cases, as with blue lupines in 1894, the yield of the crops injured most on limed soil was only one-fourth as much as the yield on unlimed soil. Cowpeas on limed soil yielded 80% in 1893 and 94% in 1894 of the yield on unlimed soil. Wheeler and Adams[4] also later noted a distinctly disadvantageous effect of lime upon lima beans. Kellerman[5] states that different legumes behave differently toward lime, lupines and seradella being injured by lime. Other investigators have noted injurious effects on different kinds of plants as will be referred to later in connection with other discussions.

EFFECT DEPENDENT UPON THE AMOUNT USED

A number of experiments have been conducted which go to show that the effect of liming depends upon the amount of lime applied. In many cases where moderate amounts may be beneficial, excessive applications have proved harmful. M. Nagaoka[6] reports injurious effects of liberal applications of lime on rice fields; and S. Suzuki[7], in conducting pot experiments, noted a decided depression on the yield of rice from excessive amounts of calcium carbonate. D. Pryaneshnikov[8] grew oats in an acid clayey soil with various amounts of lime. The oats were benefitted when lime was applied at one-fourth to one-half per cent of the weight of the soil, but when increased to one per cent, the yield was greatly reduced. This writer states that on some soils too great an amount may prove injurious to cereals.

P. S. Kossovitch[9] conducted similar experiments with various plants and found that the favorable action of lime on podzol soils increased up to a certain limit close to the amount required to neutralize the acidity. Further additions of lime, according to the plant, either made no influence or perceptibly lowered the yield. In some cases large quantities of lime ruined plants. Mustard and clover, which were more sensitive to acidity, were at first greatly benefitted, but an excess affected them injuriously. The time of introduction (immediately before or thirty days before sowing) did not modify the influence of excessive liming. The results were similar when the same plants were sown again on the soils which had received lime the previous year. Vetches and buckwheat which were used in these experiments suffered to the same extent each year.

Gardner and Brown[10] have noted an injury to clover due to excessive liming in pot experiments on soil from plots which had received various fertilizer treatments, including lime. Soil from limed plots showed a reduction in growth of clover when more lime was applied.

THE RELATION OF LIME TO PHOSPHORUS

Speculations as to the cause of the injurious effects of liming have centered around the relation of lime and phosphorus in the soil and the effects of applications of lime upon the soluble phosphates. The question has been studied under various conditions with somewhat varying results. Inasmuch as the effect of lime upon the solubility of phosphates in the

soil has been one of the subjects especially considered in the present investigation, the results of other investigators are reviewed as fully as possible. Many experiments have been conducted to show the effect of lime in connection with various phosphatic fertilizers.

M. Nagaoki[6], in order to determine the cause of the detrimental effect often observed in connection with liberal liming of rice fields, conducted a series of experiments with soil in wooden boxes to which was added caustic lime at the rate of 356 pounds per acre mixed with the soil to a depth of one foot. A large number of phosphatic fertilizers were used. From two years'work he concludes that lime exerts a retarding and unfavorable influence upon the availability of phosphoric acid of various organic manures and that the effect extends beyond the second year.

F. Westhausser and W. Zielstorf[11] found in a series of pot experiments with mustard, using 6.5 Kg of ordinary field soil poor in calcium and magnesium to which phosphoric acid in water soluble form had been applied at the rate of 50 and 100 Kg per hektare and Thomas slag at the rate of 100 Kg per hektare, that caustic lime and calcium carbonate reduced the yield in connection with the soluble phosphates and that large applications of lime reduced the efficiency of the slag.

A. Otryzanev[12] in pot experiments with oats and rye, applying phosphatic fertilizers with lime, found that the effect was satisfactory only when superphosphate was used, that in the presence of lime the action of Thomas slag was reduced,

and that the action of still more difficultly soluble phosphates (bone meal and phosphorite) was reduced to a greater extent.

B. Schulze[13] has shown the depressing effect of lime with bone meal on oats and concludes[14] that liming reduces the effect of water soluble phosphoric acid least, of citric acid soluble phosphoric acid more, and of bone phosphoric acid most. He further states that "liming injuriously affects the phosphoric acid of the soil, rendering it less soluble; the acid compounds of the soil are apparently of considerable value in rendering difficultly soluble phosphates available".

Bachman[15] concluded, after conducting plot experiments with rye, oats and beets on sandy soils fertilized with superphosphate, Thomas slag and bone meal with and without lime, that the use of lime in connection with superphosphates and bone meal results in little or no reversion of the phosphoric acid during the first year.

S. Suzuki[7] found that an excess of calcium carbonate in pot experiments with rice depressed the yield decidedly notwithstanding the fact that phosphoric acid was applied in the easily available form of sodium phosphate. On the other hand, calcium sulphate increased the yield, indicating that the carbonate depressed the assimilability of phosphoric acid. Moderate liming with bone dust did not noticeably diminish the yield.

C. A. Mooers[16] obtained results which show a distinct tendency of lime to lower the availability of rock phosphate

but not to affect acid phosphate. In other field experiments[17] with cowpeas and wheat lime decreased the relative value of both Thomas slag and rock phosphate. W. B. Ellett and H. H. Hill[18] found that calcium carbonate markedly depress the effect of phosphate in pot experiments on corn, wheat and oats.

Patterson and Scott[19] report the results of pot experiments with wheat which showed that the addition of lime increased the availability of phosphoric acid in insoluble phosphates such as wavellite and vivianite.

Following the observation of reduced yield due to applications of lime in connection with phosphatic fertilizers, several investigators in their search for the cause of the depression have endeavored to ascertain by chemical means whether lime changes the phosphates in the soil and in the fertilizers to a more insoluble form which is less available to plants. Various results have been obtained depending upon the kind of phosphorus compounds with which they worked.

W. T. Sutherst[20] found by mixing iron and aluminum phosphates with twice their weight of slaked lime in the presence of water that the solubility of the phosphoric acid was greatly increased, the results varying from 2 to 20%. Commenting on the work, Sutherst states that it is essential that the lime should be in the form of hydrate, carbonate being of no value whatever.

J. E. Greaves[21] tested the effect of soluble salts on insoluble phosphates by treating 2 g of the phosphate with

500 cc of a 1% solution of the various salts and allowed the mixture to stand ten to fourteen hours with shaking. His results showed that calcium and iron salts decreased the solubility of the phosphates.

E. W. Gaither[22] mixed calcium oxide with a soil in varying amounts and grew alfalfa on the soil in 5 gallon jars. At the end of the experiment he ascertained the amount of phosphoric acid soluble in fifth normal nitric acid. The table below gives the parts of lime applied per two million parts of soil and the amounts of phosphoric acid soluble in 5/n HNO_3

Parts CaO per 2000000 parts soil	% P_2O_5 soluble in 5/n HNO_3
Check before growth of alfalfa	.00210
Check after " " "	.00252
4000	.00225
8000	.00284
12000	.00428
16000	.00486
20000	.00720
24000	.00796
30000	.00860
36000	.00990
40000	.01094
50000	.01300

Gaither found also that Fe and Al were rendered more soluble and concludes that lime renders insoluble phosphates in the soil soluble by replacing iron and aluminum which is in conbination with the phosphorus and renders all

three more soluble in 5/n HNO_3.

Guthrie and Cohan[23] conducted experiments on three soils: 1. a light sandy soil, 2. a garden loam fairly rich in humus and 3. a very stiff clay, to determine to what extent the availability of the soil constituents is affected by the addition of lime . Ten pounds of each soil was mixed with 1% of freshly slaked lime and placed in unglazed terra-cotta pots exposed to the weather where they were allowed to remain for a month. The plant food constituents soluble in hydrochloric acid, citric acid and water were determined on the original soils and the treated soils at the end of the experiment. The results are as follows:

WATER SOLUBLE P_2O_5

	Original soil	After standing untreated 1 month	After standing limed 1 month	Increase
Sand	.0019	.0007	.0033	.0026
Loam	.0026	.0005	.0024	.0019
Clay	.0027	.0008	.0019	.0011

CITRIC SOLUBLE P_2O_5

				Increase	Decrease
Sand	.0317	.0309	.0312	.0003	----
Loam	.1674	.1815	.1792	. ---	.0023
Clay	.0405	.0426	.0241	. ---	.0185

Attention should be called to the fact that the amount of phosphoric acid soluble in water has suffered a very considerable decrease during the period of the experiment. The ac-

tion of lime has been in all cases to produce an increase in the quantities of water soluble phosphoric acid over the unlimed; but only in the sandy soil has it increased the water soluble phosphoric acid over the amount originally present in the soil. It seems that there was a steady loss of water soluble phosphoric acid during the period either by percolation through the sides of the pot or by conversion into insoluble forms. Whether the lime present prevents this reversion of the water soluble phosphoric acid or whether it renders fresh plant food soluble in water is not shown by the experiment. In case of the citric acid soluble, the quantities have not been greatly altered except in the case of the clay. The effect of liming is much less marked than with the water soluble phosphoric acid.

Further information as to the effect of lime on the water soluble phosphorus is afforded by the work of E. Rousseaux and C. Breoux[24]. These investigators set up some large pots about 30 cm in diameter in which they placed 18 kilos of soil. Enough water was added to moisten the soil. More water was added in small amounts and at frequent intervals during a period of from twelve to fifteen days, the leachings being collected for analysis. Columns of soil which had been treated with various fertilizers were leached in this way. The following table gives the results with a light sandy soil which are significant:

Treatment	Water added	Water recovered	G. P_2O_5 per liter	Total Gms. P_2O_5 Leached	Parts P_2O_5 per million of soil
No treatment	------	-------	.0153	------	------
1000 kilos slag	8.000cc	4.570	.0107	.0489	2.7

A month later the same columns were again leached with the following results:

	G. P_2O_5 per liter of soil solution
No treatment	.0182
Slag	.0073
Yet another month later	
No treatment	.018
Slag	.007

The addition of slag had the effect of diminishing, in this special soil, the content of phosphoric acid in the solution of the soil about 60%. "This effect could result in our opinion", say the writers, "only from the action of free lime in the slag which, combining with a portion of the phosphoric acid, rendered it less soluble." In order to be certain of this they conducted some experiments with liming. On February 8 the sandy soil of the untreated pot which had given regularly for nine months solutions containing from 16 to 18 milligrams of phosphoric acid per liter was limed in the proportion of 2500 kilos of quick lime per hectare; the lime and the soil were thoroughly mixed, then watered and allowed to remain untouched eight days. The soil was watered in such a manner as to slowly collect one to two liters of soil solu-

tion. At first it was watered after eight days, February 15, then at longer intervals. Following are the results obtained:

	Times drained after liming days	P_2O_5 per L mmgs.
Water collected Feb. 15	7	3.5
" " " 25	17	3.6
" " April 4	57	2.7

The effect produced by liming was very much more noticeable than that produced by the slag which contained only 200 kilos of quick lime per hectare in place of the 2500 kilos which the lime experiment furnished.

The amount of phosphoric acid soluble in citric acid in the limed and unlimed soil was determined. It was found that while the application of lime reduced the solubility of the phosphoric acid in water, the per cent indicated as assimilable by Dyer's method was not decreased.

By far the most extensive experiments to ascertain the effect of lime on the phosphorus in the soil have been a series of plot experiments conducted at the Rhode Island Experiment Station. The work is based on a series of plots to which have been applied a large number of different kinds of phosphatic fertilizers. The plots were in duplicate, one limed, the other unlimed. The experiments were begun in 1894, and annual applications of phosphatic fertilizers were made until 1902. The fertilizers applied during the eight years, 1894-1902,

amounted to 82 pounds of phosphoric acid per acre. The first application of lime was made in 1894 at the rate of one ton of air slaked per acre; and a second application at the same rate was made in 1903. Several kinds of crops have been grown on these plots each year. Wheeler[25] reports the results of 1903. The yields of Swedish turnips, German golden millet and mangel wurzel were all increased by liming with all fertilizers except the yield of millet with acid phosphate. Even after years of cropping on the plot without applications of phosphorus, on a soil which was therefore more or less exhausted in its supply of phosphorus, lime greatly increased the yield. All these results are cited as evidence that liming increased the availability of the phosphoric acid.

Hartwell and Kellogg[26] review their results in attempting by various chemical means to ascertain the availability of the phosphoric acid on the limed and unlimed plots mentioned above. In a preliminary experiment on soil from plots adjacent to those upon which the phosphate experiments were conducted, they found that hydrated lime increased the amount of water soluble phosphoric acid. This was determined by means of four 65 gram samples of soil treated as follows:

No. 1. No treatment

No. 2. .7429 g. of hydrated lime mixed with the soil (10 T per A)

No. 3. .1486 g. sodium nitrate plus .1486 g. potassium sulphate.

No. 4. .1486 g. sodium nitrate plus .1486 g. potassium sulphate plus .7429 g. hydrated lime.

After mixing, the samples were placed on double filters and leached with 20 cc portions of water until 250 cc of soil ex-

tract was obtained. From this extract the phosphoric acid was determined comparatively but not quantitatively. "The amount of color and precipitate produced by ammonium malybdate left no doubt about there being more phosphoric acid in the extract of the soil to which lime had been added than to the others." From these results the investigators concluded that some of the benefit derived from liming the Station soil is probably due to an increased amount of phosphorus. Following this experiment they determined on all plots the amount of phosphoric acid soluble in n/5 HNO_3, n/5 NH_4OH, n/25 HNO_3, n/25 NH_4OH, and n/100 NH_4OH.This work failed entirely to give results which were in any way correlated with the amounts of phosphoric acid assimilable by plants as indicated by the yields on the different plots. The conclusion was reached that it is doubtful if any solvent will extract from all soils amounts of phosphorus bearing definite relations to those removed by even a given crop.

"Having failed in extraction of the soil with nitric acid and ammonium hydroxide of different concentrations to remove such quantities of phosphorus as would serve to indicate the relative amounts of this element which, according to the crop yields, must have been available in the various plots, attention was next given to the analysis of the crops themselves. Phosphorus was determined in oats, Japanese millet, German millet and turnips from the limed plats[27]. Only in case of the turnips did the percentage of phosphorus appear to be influenced markedly by the amount available in the soil as shown by the yields of crops." In this and previous work[26], results showed that in many cases the percentage of phosphorus in the roots in-

creased with the yield, showing that more of the phosphorus in these plats was assimilable. "In no case did liming increase the rate of growth more than the rate of phosphorus absorption; that is, the percentage of phosphorus was not decreased", from which it is assumed that the supply of available phosphorus in the different plats was the limiting factor and that the increased yields were due to greater amounts of phosphorus available in the soil.

Schneider[28] also has found increased solubility of phosphoric acid on limed soil as compared to unlimed soil.

In general, the results of these investigators indicate that the effect of lime on the solubility of phosphates in the soil and in fertilizers applied to the soil depends upon the nature of the phosphates and upon the length of time during which the phosphates have been exposed to the action of the lime. With most phosphatic fertilizers and with the phosphates in the soil, the majority of investigators have found that the immediate action of the lime results in a depression of crop yields. This depressing effect is noticed especially in pot cultures where the applications are usually heavy and applied immediately before growing the crops. In considering the results of field tests at the Rhode Island Station where lime has seemed to increase the efficiency of a number of phosphatic fertilizers, it should be noted that the applications of lime had been made a year or more previous to the growth of the crops.

The results cited above seem to indicate that the effect of lime depends upon the nature of the phosphates. With

insoluble iron and aluminum phosphates the iron and aluminum are thought to be displaced by the calcium and a more readily available compound results. With readily soluble phosphates, however, the reaction with the lime apparently forms the less soluble tri-calcium phosphate. These statements seem to be borne out by the fact that the water soluble phosphates in most instances have been reduced while the amounts soluble in n/5 HNO_3 have not been reduced but in some cases increased. Lime seems, therefore, to react with the phosphates in such a way as to form compounds less soluble in water but perhaps more soluble under the stronger action of fifth normal acids. Whether this form of phosphates is available to plants can only be indicated by the crop yields. The majority of pot culture tests indicate that the efficiency of the more soluble phosphates is greatly decreased.

The depression of crop yields, however, may not necessarily be concerned with the solubility of the phosphates. Voorhees, Lipman and Brown[40] state that the cause of depression must be sought either in direct physiological interference with the assimilation processes in the plants, in decreased supply of available phosphoric acid due to applications of lime, in accumulation of injurious substances on account of more intense bacterial development brought about by lime, or in the using up of a portion of available plant food by the increased numbers of soil organisms. As to the latter, bacterial counts have shown an enormous increase of soil organisms due to lime treatment. These writers further state that lime has an important relation to phosphoric acid in the soil. In some instances,

as with iron and aluminum phosphates, the availability is increased while with calcium phosphates the availability is dedreased. Thus they explain the depressing effect of lime on the availability of the phosphoric acid in bone meal. In support of the idea that the depression is due to a physiological interference of lime with the assimilation of phosphoric acid, Keegan[44] states: "That a poor yield of certain plants on calcareous soils appears to be due to the effect of lime in preventing the assimilation of phosphorus is a result of the experiments of MM Deherain and Demoussy.--It would seem therefore legitimate to conclude that a certain proportion of lime in the soil (say 3 or 4%) is inimical to the life of certain plants which require a definite amount of phosphoric acid for the healthy performance of their physiological functions." To support this conclusion, the writer gives the analysis of the ash of the leaves of a number of plants which show an inverse ratio between calcium and phosphoric acid. Kroeber[45] explains the effect of lime in reducing the solubility of phosphates as being due to the neutralizing by the lime of the acids formed in the soil by bacteria, the action of the acids upon the phosphorus compounds being instrumental in making the phosphorus available to plants. "As long as such basic substances as lime remain in excess," says Kroeber, "they will neutralize the acids and hinder the solubility of phosphorus compounds."

THE EFFECT OF LIMING ON SOIL BACTERIA

Since the discovery of the importance of bacteria in connection with the supply of plant food in the soil, many investigators have devoted their attention to studying the activities of these organisms. It soon became evident that the amounts of lime and other basic material had a great influence upon the activities not only of various free living bacteria which fix nitrogen from the atmosphere and change the nitrogen of nitrogenous compounds into an available form, but also of the tubercle bacteria of legumes which have come to be considered of such great importance in maintaining the nitrogen supply of the soil.

According to Lipman[29], the reaction of the soil determines what species of bacteria shall flourish and a vigorous bacterial flora is not possible in soils lacking lime. Nitrate forming bacteria, he states, will not develop in the absence of lime or magnesia which serve to neutralize the nitric acid formed by the bacteria; and in the absence of these bases nitric acid accumulates until it becomes injurious to the bacteria which produce it. Hopkins[30] states, and the fact is well known by all, that most legumes, seradella and cowpeas possibly excepted, will not thrive in soils that are strongly acid. The nitrogen gathering bacteria of such legume plants do not properly develop and multiply in acid soils and consequently the legumes do not have the power which they should have to accumulate large quantities of atmospheric nitrogen by means of root tubercle bacteria. Nitrification

also is greatly promoted by the presence of limestone and retarded by acid conditions.

We give here the results of a number of investigators upon which such statements are based.

P. E. Brown[31] mixed ground limestone in various amounts from 1000 to 6000 pounds per acre and kept the soil under optimum conditions for bacterial growth. At intervals after the beginning of the experiment bacterial counts were made, the ammonifying power of the soil was tested, and the quantities of nitrates were determined. It was found that the application of ground limestone increased the number of bacteria in proportion to the amounts applied up to three tons per acre. The ammonifying and nitrifying power of the soil was proportionately increased; there were slightly increased accumulations of nitrates; and the nitrogen fixing powers of the soil were increased enormously, the increased fixation in most cases being almost directly proportional to the amounts of lime applied.

Engberding[32] found that caustic lime in liberal amounts slightly increased the bacterial content of the soil; and Vogel's results show that the activities of all soil micro-organisms are promoted by liming, which, Vogel states, explains the value of liming in increasing plant food.

Withers[33], Lyon and Bizzell[34], Krüger[35], Pryaneshnikov[8], Lipman and Brown[36], Peck[37], Fisher[38], Patterson[39], Vorhees, Lipman and Brown[40], have all found that increased nitrification resulted from applications of different forms of lime to soils under various conditions.

Ammonification also is increased by liming as shown

Vogel[41] states that lime has a beneficial influence on nitrogen fixation and estimates the minimum lime requirement of azotobacter to be 0.1% or 2000 pounds per acre 8 inches. Wohltman and Bergene[42] concluded from tests with peas on eleven different kinds of soil that lime favored the production of root tubercles.

A. V. Donnan[43] observed in plot experiments the effect of lime upon the inoculation of lucern. It was found that "lime applied to plats caused an enourmous increase in the number of plants with nodules and the number of nodules per plant. But where no bacteria were introduced lime caused practically no difference".

PLAN OF EXPERIMENTS AND METHODS EMPLOYED

The experiments under consideration in this discusdion were pot experiments conducted with mammoth clover, cowpeas, soybeans and corn on an acid soil from the vicinity of Bowling Green, Missouri. The experiments consisted of seven different series of pots, divided according to the kind of plants grown in the pots and the treatments as follows: Series 1, cowpeas; series 2, clover; series 3, soybeans; series 4, corn; series 5, soybeans inoculated; series 6, soybeans not inoculated; series 7, fallow. The cowpeas and clover were grown on soil used for the same crops the previous year by P. E. Karraker and were thus merely a continuation of his experiments. For the soybean, corn, soybean inoculated, soybean not inoculated, and fallow series new soil was used. The old soil for the cowpea and clover series is described by Karraker as follows:

"The soil was secured from just outside the Bowling Green outlying experiment field in Northeast Missouri. In type it is a gray silt loam on tight clay. The tight layer begins at 12-15 inches and extends tb a depth beyond 40 inches. A chemical analysis of the Bowling Greene soil previously made by the Experiment Station chemists gave the following results:

Soil layer	Organic matter	Total nitrogen	Acid soluble P_2O_5	Acid soluble K_2O
0-7 inches	5.77%	.175%	.236%	.292%

An acidity determination by the Veitch method of a composite sample from the soil showed that one gram of soil required 0.0012885 gms. $CaCO_3$ to neutralize the acidity. This is at the rate of 2577 lbs per 2,000,000 lbs of soil (an acre 7 inches).

Only the surface seven to eight inches was used. When secured the soil was in grass sod. It was secured directly after a heavy rain and while it was still almost muddy."

The new soil was obtained by the writer on November 12, 1913, from the farm of W. B. McPike about a mile southwest of Bowling Greene, Missouri, the particular location being from the field about a quarter of a mile southeast of the Bowling Greene experiment field. Corn had been grown on the field in 1913 and was cut for fodder. At the time the soil was taken it was almost saturated with moisture from recent rains and became puddled to some extent in handling and shipping. The soil was shipped in jute wheat sacks from which it was emptied and spread out on a bench in the green house to dry as soon as it arrived. The description quoted from Karraker will suffice for this soil also. As soon as the moisture had evaporated sufficiently, the soil was sifted through a one-fourth inch mesh sieve. Thereafter it was stirred daily until it became air dry. It was then shoveled onto a wooden platform and reshoveled five or six times so that it became as thoroughly mixed as possible. A large sample for

future analysis was taken at this time by passing a sampling tube several times through the pile of soil at different places and in different directions both vertical and horizontal.

Lime requirement determinations by the Veitch method showed that it required about .98 mmg. of CaO per gram of soil to neutralize the acidity, which is equivalent to 3500 lbs of calcium carbonate per acre 7 inches (2,000,000 lbs of soil). The ground limestone used in these experiments was secured from Ellis Brothers of Elsberry, Missouri. Only that part which passed through a 100 mesh sieve was used.

Wherever nitrogen was used as a fertilizer on any pots, it was added in dried blood containing 12.84% nitrogen. The phosphorus added was in the form of steamed bone meal analyzing 1.17% nitrogen and 30.66 % P_2O_5. All potash added was in the form of potassium sulphate.

The pots used were ordinary three gallon glazed earthenware jars. Three inch porous flower pots in the bottom of each jar for watering through glass tubes constituted the remainder of the apparatus.

The seed used was as follows: Black cowpeas grown on the experiment station field 1913, mammoth red clover from the same supply as was used by Karraker the previous year, Reid's Yellow Dent corn, and medium yellow soybeans obtained from a supply at the agronomy seed-room.

Distilled water only was used in watering the plants throughout the experiment.

TREATMENT OF SERIES 1 AND 2 COWPEAS AND CLOVER ON OLD SOIL

As already mentioned, the soil used with these series had grown the same crops the previous year in a similar pot experiment conducted by P. E. Karraker, who describes the treatment as follows:

"9247 gms. of the air dry soil was used per pot. The complete fertilizer treatment is shown in the following table:

Series 1, 1 gm bone meal 1 gm K_2SO_4

Series 2, 30 gms limestone, 1 gm bone meal, 1 gm K_2SO_4

Series 3, 75 gms limestone, 1 gm bone meal, 1 gm K_2SO_4

Series 4, 75 gms limestone, 5 gms dried blood, 1 gm bone meal, 1 gm K_2SO_4

The inoculating material and fertilizers, excepting the potassium sulphate, were well mixed with the soil before putting in the jars. The potassium sulphate was added in solution afterwards. The pots used for cowpeas grew two crops, while only one crop of mammoth clover was grown. Before planting the second crop of cowpeas an additional 1 1/2 gram of bone meal and likewise of K_2SO_4 was added to each pot."

The soil remained in the jars in the green house during the summer and was quite dry when taken for use in this experiment in October 1913. The triplicates of each

treatment were sifted through a sieve made of ordinary window screen and mixed together thoroughly. There remained enough soil of each treatment to run duplicates of 10,000 grams each with the clover and of 9000 grams with the cowpeas except treatment 1, the no lime treatment. Of this soil there was only 17250 grams. To make up this deficiency, 750 grams of soil from fallow pots of the same treatment was used. The soil of the fallow pots 1 a, b and c was sifted and mixed together as thoroughly as the other soil. 750 grams of this soil was thoroughly mixed with the cowpea soil making 18000 grams, or enough to run duplicates of 9000 grams each. No further treatment was given to the soil in this experiment as the experiment was conducted to observe the after effects of the treatment given a year before.

Before placing the soil in the jars, a three inch porous flower pot was inverted in the bottom of each jar with a three-eighths inch glass tube extending up through the hole in the flower pot to a convenient height slightly above the top of the jar. This arrangement was for the purpose of watering the plants without puddling the surface of the soil, the water being added through the glass tube instead of being poured on to the surface of the soil.

The seeds were planted in the dry soil, the cowpeas, 20 seeds in each pot, being pushed down about an inch deep and the clover covered with a shallow layer of dust. Distilled water was then poured over the surface of the soil and allowed to soak in. The amount added was calculated to give the soil an optimum moisture content of 20%. Thus 1800 cc was added

to each pot of the cowpea series and 2000 cc to the clover series. The cowpeas were planted November 14 and the clover November 15.

The seed soon germinated and a good stand of healthy looking plants came up in each jar. The clover was gradually thinned down to twenty plants per pot; the cowpeas were thinned down to twelve plants, the entire plant being removed; and seeds that failed to germinate were dug up so that they might not be taken in future samples of the soil and affect the analyses.

After the plants had attained some height, the surface of the soil was carefully mulched and kept in this condition throughout the experiment. At the end of each week enough water was added to bring the pots up to the original weight with an optimum moisture content. Near the end of the experiment the clover was watered twice a week.

The cowpeas were harvested January 30, the clover March 14. It was not possible to secure the roots of the cowpeas; but the roots and tops of the clover were harvested separately.

TREATMENT OF SERIES 3 AND 4
SOYBEANS AND CORN

In this experiment the purpose was to observe the effect of ground limestone in connection with a liberal amount of phosphorus supplied by bone meal.

All pots contained 10,000 grams of air dry soil.

The treatments given are shown in the following table, each treatment being run in duplicate

1,		1 g. K_2SO_4; 2 1/2 g. dried blood
2,	27 1/2 g. ground limestone	" " " " " " "
3,	10 g. steamed bone meal	" " " " " " "
4,	27 1/2 g. limestone, 10 g. bonemeal	" " " " " " "

The bone meal added to treatments No. 3 and No. 4 was at the rate of 2000 lbs per acre 7 inches (2,000,000 lbs soil). The ground limestone was at the rate of one ton per acre above the amount found necessary to neutralize the acidity. All fertilizers except the potassium sulphate were mixed with the soil before it was placed in the jars. The potassium sulphate was added in solution afterwards. The soybeans were inoculated in the same manner as described for series 5.

The jars were set up with the device for watering as already described. The seeds were planted December 19 and 2500 cc of water was added to each jar. Owing to the puddling of the soil, most of the seeds rotted. They were dug out, the soil mulched and the pots were replanted January 7. The application of 2500 cc of water seemed to be too much; so the pots were kept at a water content of 2000 cc thereafter. When the plants had attained sufficient size, they soybeans were thinned to six plants per pot and the corn to three plants per pot. The roots and tops of the plants in each pot were harvested separately March 23.

TREATMENT OF SERIES 5, 6 AND 7, SOYBEANS INOCULATED, SOYBEANS NOT INOCULATED AND FALLOW.

This series of experiments was conducted for the special purpose of observing the effect of different amounts of ground limestone both with and without liberal nitrogenous fertilizers on the growth of root tubercle bacteria and the effect of inoculation on the growth of soybeans under the different treatments.

All pots contained 10,000 grams of air dry soil. The treatments given are shown in the following table, each treatment being run in duplicate:

1,			1 g. K_2SO_4;	2 1/2 g. bone meal
2,	27 1/2 g. ground limestone		" " "	" " " "
3,	67 1/2 " " "		" " "	" " " "
4,		5 g. dried blood	" " "	" " " "
5,	27 1/2 g. " "	" " " "	" " "	" " " "
6,	67 1/2 g. " "	" " " "	" " "	" " " "

The ground limestone added to treatments No. 2 and No. 5 was at the rate of one ton above the amount necessary to neutralize the acidity; that added to treatments No. 3 and No. 6 was at the rate of five tons above the lime requirement. The dried blood added to treatments No. 4, No. 5 and No. 6 amounted to 1000 lbs per acre 7 inches. The fertilizers were applied as described for series 3 and 4. Series 5 was inoculated by mixing with the soil of each pot about 75 grams of soil taken in December

from block K on the experiment field where soybeans had grown the previous season. In addition to this, the seeds which were first planted were inoculated with the liquid culture furnished by the U. S. Department of Agriculture.

As with series 3 and 4 these pots had to be replanted on January 7. The amount of water added to each pot which was at first 2500 cc was reduced to 2000 cc. The soybeans were thinned down to six plants per pot. All plants were harvested March 23, keeping roots and tops separate.

THE EFFECT OF LIME ON THE GROWTH OF THE PLANTS

The effect of ground limestone on the growth of the plants was quite noticeable in the early part of the period. On series 1 where cowpeas were grown the second year after the treatment, the pots which had received limestone at first appeared much thriftier than those growing on the unlimed soil. They were much larger in size and had a healthy green color. The size, however, did not range according to the amounts of lime applied but in inverse ratio. The largest plants grew on the soil receiving moderate lime. Those growing on the heavy limed soil were noticeably smaller, and the plants growing on the soil which had received a heavy application of dried blood in addition to heavy lime were still smaller. The plants on the unlimed soil were at first the smallest of the entire series and the first leaves were spotted with yellow, finally turning brown and dying in spots. As the leaves grew, these dead spots caused the leaves to wrinkle and to develop unevenly. As growth continued, however, the plants on the unlimed soil rapidly recovered from the unhealthy condition which they first showed and were soon as large as the best plants on the limed soil. The accompanying photograph Plate I shows the plants of this series after about five weeks growth.

When the plants were about eight weeks old, those growing in the soil receiving dried blood began to show signs of being attacked by cowpea wilt and the plants soon began to

die. On January 17 only three plants remained in pot 4b and only seven remained in 4a. Plants on the other pots began to show signs of being affected in the same way and were, therefore, harvested January 30 when the plants were just beginning to bloom. At this time the cowpeas on the unlimed soil were the largest of the series.

The mammoth clover on series 2 which had grown clover the previous year showed the same marked differences in growth at the beginning of the experiment. The plants on the unlimed soil were decidedly inferior in size and lacked the healthy green color possessed by the plants on the limed soil. The largest plants grew on the soil which had received a moderate amount of lime (one ton in excess of the lime requirement). Plants on the heavy limed soil were next in size and the plants on the soil receiving 1100 lbs of blood meal per acre in addition to a heavy application of limestone ranked third in size. This order was maintained throughout the experiment though the differences were not so great at the time of harvesting. Plate II shows the clover at the time of harvesting.

In series 3 where soybeans were grown with and without a liberal amount of bone meal both on limed and unlimed soil immediately after the soil was treated, there was a depression of growth due to liming in each case as can be seen in Plate III.

In series 4 where corn was grown under the same treatment as was given in series 3, the growth was again de-

pressed by limestone both with and without the bone meal. In this case the differences were more marked in the early stages of growth than at the end of the experiment. At the time the plants were harvested, the height of the corn on limed soil was about equal to the height of the plants on the unlimed soil. The plants, however, were more slender and weighed considerably less.

Plate IV shows the corn as it appeared when the experiment ended.

In series 5 and 6 soybeans were grown with different amounts of limestone, both with and without the application of a liberal amount of dried blood. The two series received identical treatment except that series 5 was inoculated while series 6 was not. In both series there was a depression of growth due to the limestone in proportion to the amount added, though the differences were not marked. Plate V illustrates very well the appearance of series 5 at the end of the experiment. Series 6 showed practically the same differences.

The amount of water transpired by plants is sometimes taken as a rough measure of the growth which takes place. In the following table is given the relative amounts of water transpired by the plants in all the series. The amount transpired by the untreated plants is taken as 100. With series 3, 4, 5 and 6, the average amount of water evaporated from the fallow pots was subtracted before the comparisons were made. With series 1 and 2 there were no fallow pots of corresponding treatment, hence it was not possible to estimate the amount of water by evaporation.

TABLE I

RELATIVE AMOUNTS OF WATER TRANSPIRED BY PLANTS OF ALL SERIES

Old Soil

Treatment	Cowpeas Series 1	Clover Series 2
1. No lime	100	100
2. Lime, 1 ton excess	102	122
3. Lime, 5 tons excess	88	114
4. Lime, 5 tons excess plus dried blood	70	112

New Soil

	Soybeans Series 3	Corn Series 4
1. No lime	100	100
2. Lime, 1 ton excess	60	48
3. Bone meal, no lime	167	280
4. Bone meal, lime 1 ton excess	140	121

	Soybeans Inoculated Series 5	Soybeans not Inoculated Series 6
1. No lime	100	100
2. Lime, 1 ton excess	85	70
3. Lime, 5 tons excess	63	64
4. Dried blood, no lime	87	105
5. Dried blood, lime 1 ton excess	70	70
6. Dried blood, lime 5 tons excess	60	74

There is a general agreement between the amount of water transpired and the growth. However, the agreement is not close and no particular significance can be attached to these figures as it is not possible to account for the exact

amounts of water lost by evaporation from the various pots.

In harvesting the plants the tops were cut off at the surface of the soil; and the roots and tops were harvested separately except with the cowpeas in series 1 where the roots were practically destroyed by disease.

The weights given in the following table are of the air-dry plants.

TABLE 2

CROP YIELDS AIR-DRY WEIGHT OF

TOPS AND ROOTS

Old Soil

Treatment	Pot No.	Cowpeas Series 1	Clover Series 2
1. No lime	A	10.55 gms	17.56 gms
	B	10.50	16.50
	Total	21.05	34.06
2. Lime, 1 ton excess	A	9.00	24.14
	B	10.00	23.03
	Total	19.00	47.17
3. Lime, 5 tons excess	A	9.20	22.54
	B	11.10	23.08
	Total	20.30	45.62
4. Lime, 5 tons excess, dried blood	A	5.70	21.07
	B	5.55	20.60
	Total	11.35	41.67

TABLE 2 (CONTINUED)

New Soil

Treatment	Pot No.	Soybeans Series 3	Corn Series 4
1. No lime	A	7.85 gms	10.60 gms
	B	6.21	8.50
	Total	13.06	19.10
2. Lime, 1 ton excess	A	5.73	9.25
	B	5.67	8.20
	Total	11.40	17.45
3. Bone meal, no lime	A	13.60	44.20
	B	13.49	42.30
	Total	27.09	86.50
4. Bone meal, lime 1 ton excess	A	10.74	28.50
	B	9.70	29.20
	Total	20.44	57.90

Treatment	Pot No.	Soybeans Inoculated Series 5	Soybeans Not inoculated Series 6
1. No lime	A	9.56	8.55
	B	7.87	9.67
	Total	17.43	18.22
2. Lime, 1 ton excess	A	8.90	7.54
	B	7.25	8.24
	Total	16.15	15.78
3. Lime, 5 tons excess	A	8.01	6.51
	B	7.77	8.02
	Total	15.78	14.53
4. Dried blood, no lime	A	9.93	9.18
	B	8.77	8.80
	Total	18.70	17.98
5. Dried blood, lime 1 ton excess	A	7.78	6.88
	B	7.80	8.11
	Total	15.58	14.99
6. Dried blood, lime 5 tons excess	A	7.46	7.25
	B	7.11	8.03
	Total	14.57	15.28

Considering the clover grown on soil a year after the lime treatment, it is seen that the limestone in all cases produced a considerable increase in the yield. The yield, however, was greatest with the lighter application of limestone, the heavier application being less beneficial, and the heavier liming in connection with a liberal amount of dried blood giving a still smaller increase in yield.

On account of the cowpeas being attacked by disease, the final weights of this crop can hardly be considered of much importance in showing the effect of lime. The early stages of growth of the cowpeas, however, showed the same differences as were observed in the clover.

In every case where the crops were grown immediately after the application of lime (series 3, 4, 5 and 6), the lime caused a depression in the yield of the crops. Moveover, the difference was proportional to the amount of lime applied in all cases except one - treatment No. 6 on the uninoculated soybean series, in which case the yield on the soil receiving five tons of limestone in excess of the lime requirement was slightly more than on the soil receiving an excess of one ton. The difference is less than 2% and may easily be due to accidental variation in the vigor of the plants.

In this connection reference should be made to the results obtained by P. E. Karraker on the clover and soybean series the previous year, that is, with crops grown immediatly after the application of the limestone. His results also showed a depression of the yield of clover and soybeans as a

result of the limestone the first year, the depression being proportional to the amount applied.

In all these experiments the amounts of limestone applied were in excess of the lime requirement of the soil and may be considered heavy applications. Whether applications of lime in amounts not exceeding the lime requirement would cause a depression in yield can only be surmised.

The results show conclusively that applications of ground limestone in amounts much in excess of the lime requirement of a soil may result in a depression of the yield of certain crops grown immediately after the application and under the conditions which obtained during these experiments. The results indicate, also, that similar depressions of crop yields might at first result from heavy applications of limestone under field conditions.

A comparison of the results of the clover on series 2 with the results obtained by Karraker on the same soil the previous year seems to indicate that the injurious effect upon crops of heavy applications of limestone disappears in time, the heavier the application the longer the time required for the injurious effect to disappear.

The behavior of the corn grown in series 4 indicates also that a crop may recover from the injury at first suffered as a result of an excess of lime in the soil.

THE EFFECT OF LIME ON NITRIFICATION

Determinations of the amounts of nitrate in the soil at the beginning and the end of the experiments were made by the colorimetric method described in bulletin 31 of the U. S. Bureau of Soils. The following table shows the amounts of nitrate found:

TABLE 3

AMOUNTS OF NITRATE IN THE SOIL AT BEGINNING AND END OF EXPERIMENT, CALCULATED IN PARTS PER MILLION OF AIR-DRY SOIL.

Old Soil

Treatment	Cowpeas Series 1 Beginning	End	Clover Series 2 Beginning	End
1. No lime	38.0	10.4	13.8	0
2. Lime, 1 ton excess	50.0	40.0	24.4	0
3. Lime, 5 tons excess	140.8	163.3	105.8	27
4. Lime, 5 tons excess plus dried blood	270.0	296.5	157.5	164

New Soil

	Soybeans Series 3 Beginning	End	Corn Series 4 Beginning	End
1. No lime	20	108.7	20	55.5
2. Lime, 1 ton excess	20	172.4	20	80.0
3. Bone meal, no lime	20	90.9	20	15.5
4. Bone meal, lime 1 ton excess	20	152.0	20	77.0

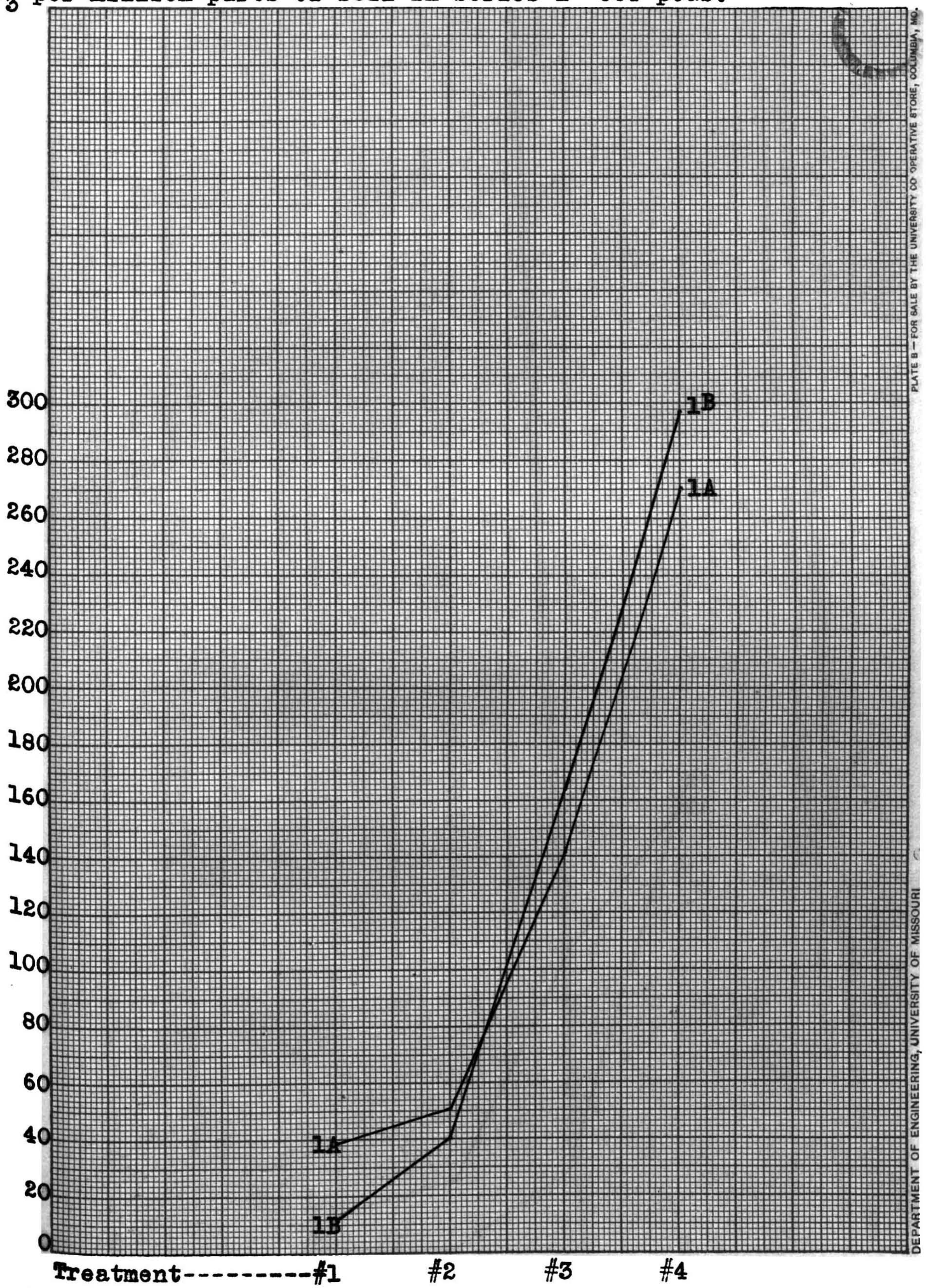
TABLE 3 (CONTINUED)

Treatment	Soybeans Inoculated Series 5		Soybeans not Inoculated Series 6		Fallow Series 7	
	Beginning	End	Beginning	End	Beginning	End
1. No lime	20	60	20	57.5	20	65.6
2. Lime, 1 ton excess	20	106.6	20	95.25	20	106.6
3. Lime, 5 tons excess	20	161.3	20	166.6	20	156.25
4. Dried blood, no lime	20	141.3	20	132.4	20	150.
5. Dried blood, lime 1 ton excess	20	194.2	20	192.3	20	250.
6. Dried blood, lime 5 tons excess	20	279.0	20	270.0	20	382.5

The amounts of nitrate found in the soil are illustrated graphically in the accompanying diagrams.

Diagram #1

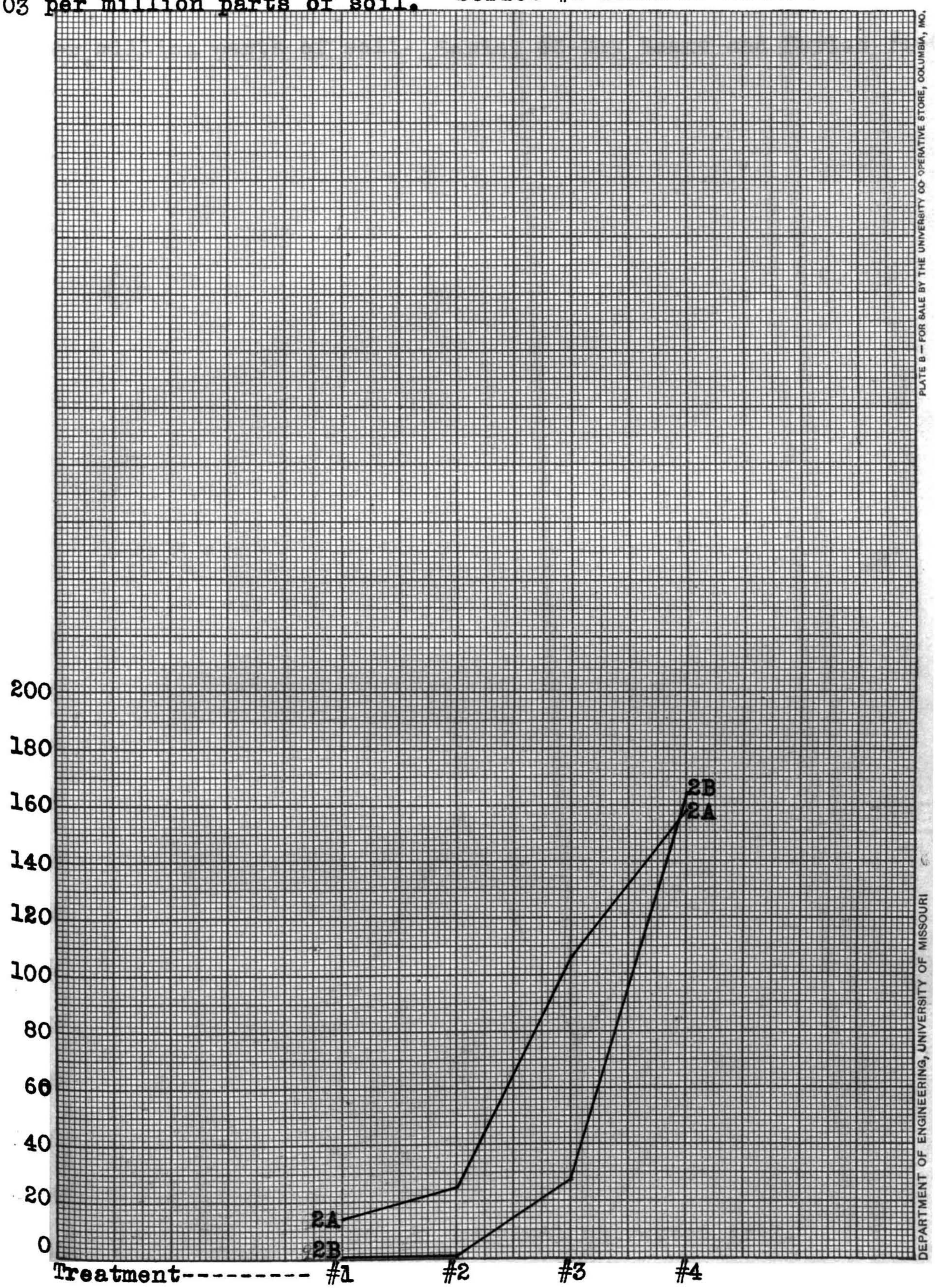
NO_3 per million parts of soil in series 1- cow peas.



Line 1A- NO_3 at beginning of experiment.
Line 1B- " " end " "

Diagram #2

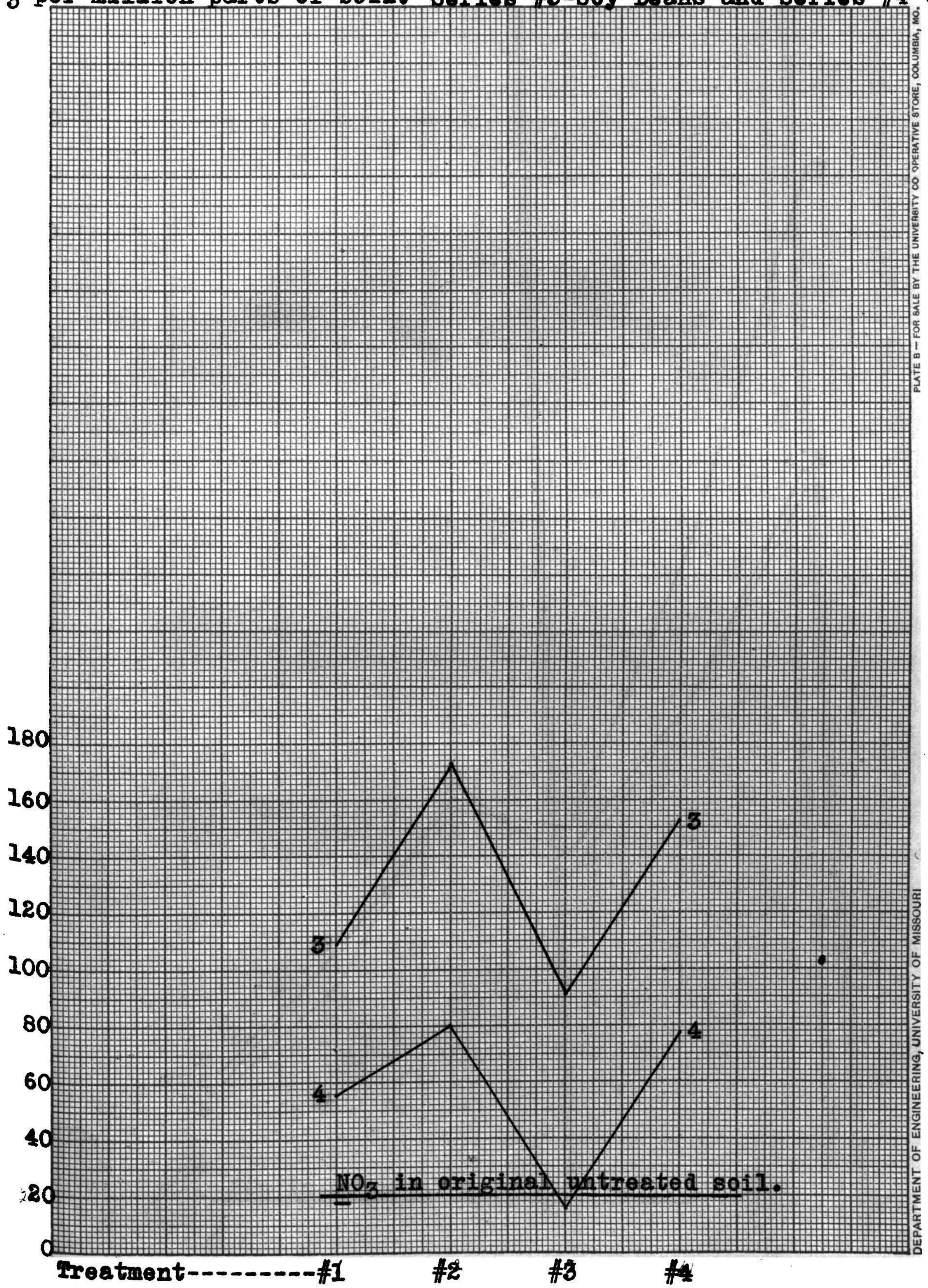
NO_3 per million parts of soil. Series #2 Mammoth Clover.



Line 2A- NO_3 at beginning of experiment.
Line 2B- " " end " "

Diagram #3

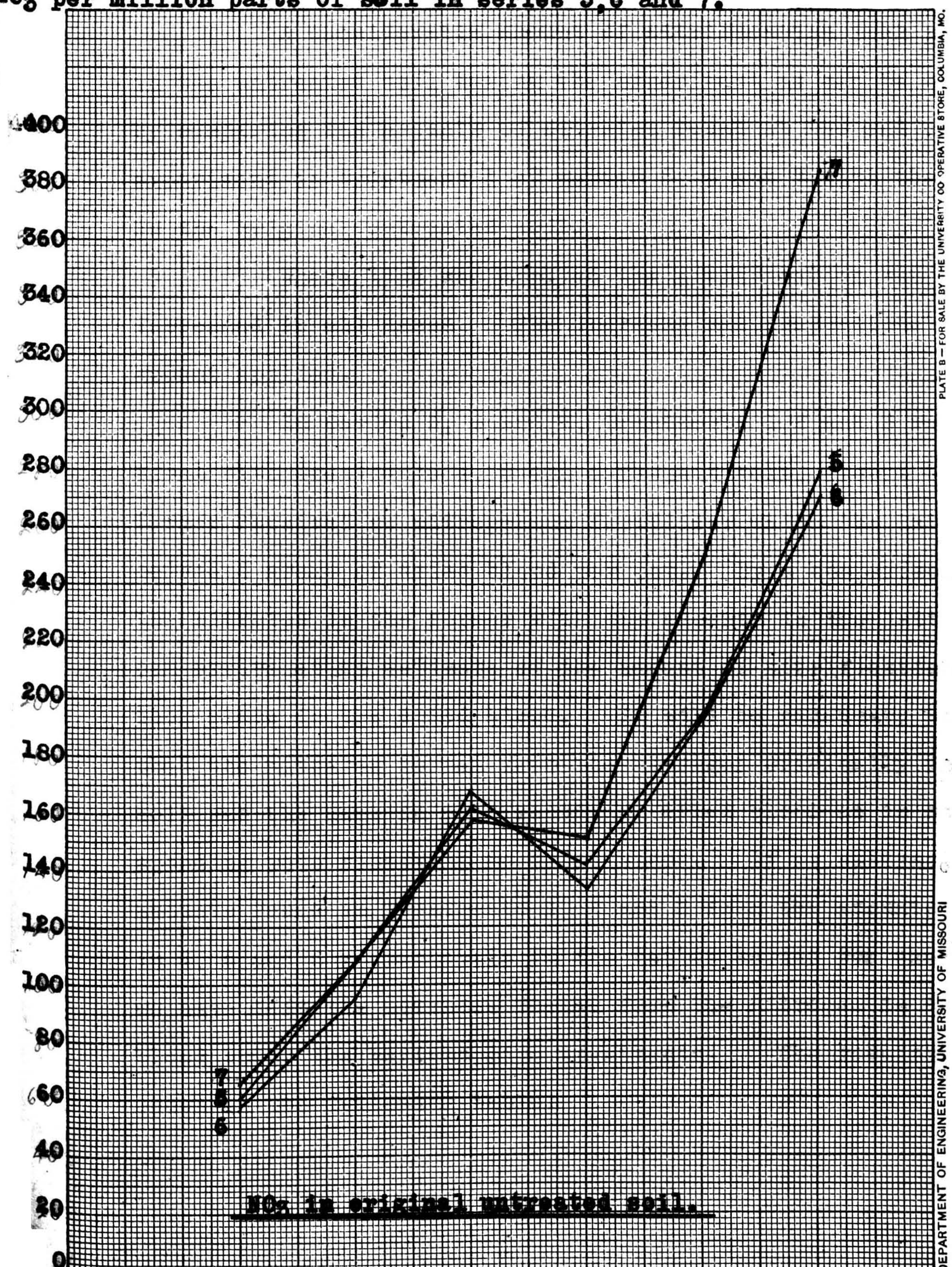
NO_3 per million parts of soil. Series #3-Soy Beans and Series #4-Corn.



Line 3- NO_3 in series #3 at end of experiment.
Line 4- " " " #4 " " " "

Diagram #4

NO_3 per million parts of soil in series 5, 6 and 7.



Treatment-#1 #2 #3 #4 #5 #6

Line 5-NO_3 in series 5 at end of experiment.
Line 6 " " " 6 " " " "
Line 7 " " " 7 " " " "

A considerable amount of nitrification took place in the untreated soil during the experiment as can be seen by comparing the amounts of nitrates found at the end of the experiment in treatment 1 of series 5, 6 and 7 with the amount in the original untreated soil.

Where lime was applied the nitrification was greatly increased in all cases. The increase was proportional to the amount applied.

In series 5, 6 and 7, treatments 1, 2 and 3 were identical with treatments 4, 5 and 6 réspectively, except that the former received no nitrogenous fertilizer while the latter received 5 grams of dried blood per pot. By a comparison of the nitrates in the former with the amounts in the latter, we can arrive at an estimate of the amount of nitrification which took place in the dried blood. It will be necessary to assume that the nitrates formed from the nitrogen originally in the soil was the same in pots receiving dried blood as in corresponding pots receiving no dried blood. If we subtract the amounts found in treatments 1, 2 and 3 from the amounts found in 4, 5 and 6 respectively in the fallow series for example, we have left the nitrates formed from the nitrogen in the dried blood under the various lime treatments. The results are shown in the following table:

TABLE 4

NITRIFICATION OF DRIED BLOOD UNDER VARIOUS APPLICATIONS OF LIME.

Lime treatment	No lime	Lime 1 ton in excess	Lime 5 tons in excess
	Parts NO_3	per million	parts of soil
NO_3 with dried blood	150.0	250.0	382.50
NO_3 without dried blood	65.6	106.6	156.25
NO_3 formed from dried blood	84.4	143.4	226.25
Grams NO_3 per pot	.844	1.434	2.263
Equivalent in gms N	.1906	.3238	.5109
Grams N added in dried blood	.6420	.6420	.6420
% N in blood changed to NO_3	29.7	50.4	79.6
Increase in nitrification on limed treatments over nitrification in unlimed soil		70. %	168. %

As the data shows, 29.7% of the nitrogen in the dried blood was converted to nitrates in the soil where no lime was added. Fifty and four tenths per cent was converted to nitrates in the soil treated with 1 ton of lime in excess of the lime requirement; and 79.6% of the nitrogen was nitrified where the soil was treated with an excess of 5 tons of lime. The increase in nitrification due to lime was 70% with the application of 1 ton in excess and 168% where 5 tons in excess was applied.

A considerable amount of nitrates was of course removed from the cropped soil by the crops. In series 1 treatments 1 and 2, in series 2 treatments 1, 2 and 3 and in series 4 treatment 3 there was less nitrate at the end of the experiment than at the beginning, thus more nitrates were

removed by the crops than were produced in the soil during the experiment. In all other instances the rate of nitrification exceeds the rate at which the nitrates were removed by the crops.

The above mentioned cases where less nitrates were found at the end of the experiment than at the beginning were in connection with the unlimed or lightly limed soils and where the crops were heavy, as for example in series 4, treatment 3, where there was a heavy crop of corn on unlimed soil.

The results show, as many other investigators have found, that lime increases the nitrification in soils to which it is applied, the rate of increase being proportional to the amount of lime applied.

THE EFFECT OF LIME ON INOCULATION

In the studies on inoculation, it was intended to compare the effect of lime on inoculation the second year after the application with the effect immediately following the application. This was done by comparing the results on the clover series 2 with the results observed by P. E. Karraker on the same crop and soil the previous year. Series 5 was planned to observe the effect of a liberal supply of nitrogen with various amounts of lime as well as the effect of lime alone.

The nodules on the roots of the clover and soybeans were counted; and those on the soybean roots were weighed when

air dry. The results are recorded in the following table:

TABLE 5

NUMBER OF NODULES FOUND ON CLOVER AND SOYBEAN ROOTS AND AIR-DRY WEIGHT OF NODULES ON SOYBEAN ROOTS.

Clover, Series 2

Treatment	Pot No.	No. of Nodules
1. No lime	A	1217
	B	1151
	Total	2368
2. Lime, 1 ton excess	A	2487
	B	2603
	Total	5090
3. Lime, 5 tons excess	A	1825
	B	1975
	Total	3800
4. Lime, 5 tons excess dried blood 1100#	A	1875
	B	1985
	Total	3860

Soybeans, Series 3

Treatment	Pot No.	No. of Nodules	Wt. of Nodules
1. No lime	A	3	.021 g
	B	3	.015
	Total	6	.036
2. Lime, 1 ton excess	A	11	.017
	B	4	.005
	Total	15	.022
3. Bone meal, no lime	A	6	.051
	B	2	.025
	Total	8	.076
4. Bone meal, lime 1 ton excess	A	16	.144
	B	10	.109
	Total	26	.253

Soybeans, Series 5

	Pot No.	No. of Nodules	Wt. of Nodules
1. No lime	A	15	.190
	B	12	.046
	Total	27	.236
2. Lime, 1 ton excess	A	18	.190
	B	10	.080
	Total	28	.270
3. Lime, 5 tons excess	A	5	.026
	B	6	.022
	Total	11	.048
4. Dried blood, no lime	A	5	.030
	B	1	.005
	Total	6	.035
5. Dried blood, lime 1 ton excess	A	7	.020
	B	6	.016
	Total	13	.036
6. Dried blood, lime 5 tons excess	A	4	.005
	B	5	.009
	Total	9	.014

The clover was well inoculated as can be seen by the number of nodules on the roots. The roots in the unlimed treatment were rather small and slender; and the nodules were distributed only on the lower roots near the bottom of the jar and around the small flower pot which was inverted in the bottom of the jar. Under the moderate lime treatment the roots were stocky and well branched and the nodules were well distributed over all the roots, although most of the nodules were near the surface and around the flower pot in the bottom of the jar where aeration was best. The nodules under this treatment were noticeably larger than those under the other treatments. Those under treatment 3 were distributed about like those under treatment 2 but were somewhat smaller. Under treatment 4 the

nodules were very noticeably smaller than any of the others.

Only a fair inoculation of the soybeans was obtained on series 3 and 5. With series 6 which was not artificially inoculated, only two nodules were found in the twelve pots. Plate VI illustrates the inoculation in series 5 and 6.

The results on all the series show that the best inoculation took place where the lighter application of lime was made. In every case the number of nodules averages greater under this treatment; and the weight of nodules is also greater except in series 3 where it is slightly less than the weight of nodules from the unlimed pot. These results agree with the results found by Karraker as to the number of nodules except in the clover series, in which he found the best inoculation in the unlimed soil. The weights of nodules, however, do not agree with his results, He reports the greatest weight in all cases on the unlimed soil, the weights decreasing in the order of the treatment throughout the series. The heavier application of limestone in all cases reduced both the number and weight of nodules.

In the soybean series 5 where a liberal amount of dried blood was added in connection with the various lime treatments, the number and weight of nodules were much less in the pots receiving dried blood than in pots having the same lime treatments without the dried blood. In the clover series also the nodules in the soil which had received dried blood were much smaller in size than those under the other treatments, although the number was practically the same as in the pot

having the same lime treatment without the addition of dried blood.

These results seem to indicate that a large supply of nitrogen in the soil is injurious to inoculation of legumes and to the growth of the tubercle bacteria. It also seems to shed some light upon the cause of the depressing effect on inoculation due to excessive amounts of lime in that it suggests that the injurious effect is due to the large amounts of nitrates produced by the heavy applications of lime.

The results in general show that limestone applied to an acid soil in amounts not greatly exceeding the lime requirement of the soil is beneficial to root tubercle bacteria and facilitates the inoculation of legumes.

The results further indicate that excessive amounts of limestone applied to an acid soil may prove harmful to the tubercle bacteria and hinder the inoculation of legumes. This effect may be due to the excessive production of nitrates when limestone is applied in large amounts.

In connection with the studies of inoculation some interesting observations on the influence of tubercle bacteria in supplying nitrogen to the host plant may be made. A reference to Diagram 4 shows that the amount of nitrates found at the end of the experiment in the soil of the inoculated series (line 5) was slightly more than that found in the uninoculated series (line 6) except in case of treatment No. 3. The difference is not great but, with the single exception noted, is fairly consistent. This difference might be considered as being due to the bacteria supplying a part of the nitrogen used by the plants.

It would seem, therefore, that lime in amounts which are beneficial to the root tubercle bacteria may play an important part in nitrogen fixation in the soil by facilitating the growth of tubercle bacteria.

THE EFFECT OF LIME ON PHOSPHATES IN THE SOIL

As already described, the treatment of series 3 and 4 consisted of limed and unlimed soil both with and without a heavy application of bone meal, the purpose of this experiment being to observe the effect of a liberal amount of ground limestone in connection with phosphatic fertilizers.

The effects of the different treatments on growth are shown in Table 2, page 40. On soil without bone meal, an application of lime amounting to 1 ton more than the lime requirement reduced the yield of soybeans from 13.06 gms to 11.40 gms, or 12.7%, and the yield of corn from 19.10 gms to 17.45 gms, or 8.6%. In connection with the bone meal, the same application of limestone reduced the yield of soybeans from 27.09 gms to 20.44 gms, or 24.5% and the yield of corn from 86.50 gms to 57.90 gms, or 33%.

The results agree with those of many other investigators in showing the depressing effect on the growth of plants due to heavy applications of lime, especially in connection with phosphatic fertilizers. In explanation of this effect, it has been suggested that the lime reduced the amount of available phosphoric acid in the soil and fertilizers applied by fixing it in a less available form. With the hope of obtaining information which might shed some light upon the value of this suggestion, attempts were made to determine the amounts of water soluble phosphoric acid in the soil of the

different treatments at the end of the experiment. Difficulty was found in deciding upon a method which seemed sufficiently accurate to give conclusive results but the colorimetric method described by Shreiner and Failyer in bulletin 31 of the U. S. Bureau of Soils was finally adopted. Two hundred grams of soil was placed in a 2 1/2 liter reagent bottle with 1000 cc of water and shaken at intervals during 20 to 24 hours. The solution was then filtered clear and 500 cc of the clear filtrate was evaporated down in making the determination. The results obtained were as follows:

TABLE 6

AMOUNTS OF WATER SOLUBLE P_2O_5 IN SERIES 3 AND 4 AT END OF EXPERIMENT PARTS P_2O_5 PER MILLION PARTS OF SOIL.

Treatment	Soybeans Analysis No. 1	2	3	Corn Analysis No. 4	5
1. No lime	4.16	23.80	8.62	8.62	9.09
2. Lime, 1 ton excess	4.16	10.00	5.90	10.00	9.09
3. Bone meal, no lime	6.25	23.53	11.11	7.80	15.66
4. Bone meal, lime 1 ton excess	4.50	8.58	11.11	6.40	11.36

In some trials, more phosphoric acid was obtained than in others, which was probably due to differences in the time and amount of shaking. The readings for treatment 4 run 3, treatment 2 run 4, and treatment 2 run 5 were undoubtedly higher than they should have been on account of a brown-

ish color which appeared in the solutions before the color due to the reaction of the phosphate and ammonium molybdate was developed, thus making the color appear more dense. Barring these discrepancies, the results show that in all cases but one on the soil without bone meal the amount of water soluble phosphoric acid was found to be less where lime was applied than in the unlimed soil; and in the soils receiving bone meal, the amount of water soluble phosphoric acid found in the limed soil was in all cases less than that found in the unlimed soil. It must be admitted that the method did not give entirely satisfactory results. Notwithstanding this, however, the fact that in all cases where clear solutions were obtained less color was developed from the limed samples than from the unlimed samples leaves no doubt that the amount of water soluble phosphoric acid was decreased by the lime.

The results seem to indicate, therefore, that the depressing effect on the growth of plants which results from heavy applications of lime to the soil may be caused, at least in part, by a decrease in the amount of available phosphates brought about by the reaction of the lime with the more readily available phosphates in the soil.

SUMMARY

Applications of ground limestone to an acid soil in amounts as great as 1 ton or more in excess of the lime requirement of the soil, as shown by the Veitch method, decreased the yield of certain crops grown in pot cultures immediately after the application of the limestone.

The decrease in yield was roughly proportional to the amount of limestone applied.

From these results, it seems probable that similar depressions of crop yields might also result from heavy applications of lime under field conditions.

The injurious effect upon crops of heavy applications of limestone seems to disappear in time, the heavier the application the longer the time required for the effect to disappear entirely.

Applications of limestone greatly increase the amount of nitrates produced in the soil.

The nitrification of the nitrogen in dried blood is greatly accelerated by applications of lime.

The increase in nitrification is, in general, proportional to the amount of limestone applied within the limits observed in these experiments.

Ground limestone applied to an acid soil in amounts not greater than 1 ton in excess of the lime requirement seems to favor the inoculation of certain legumes and the growth of root tubercle bacteria.

Limestone in amounts as great as 5 tons in excess of the lime requirement, however, seems to inhibit inoculation of legumes and to have an unfavorable effect upon the growth of root tubercle bacteria.

Excessive amounts of nitrates in the soil are unfavorable to inoculation of legumes and to the growth of the tubercle organisms.

The injurious effect upon inoculation and the growth of root tubercle bacteria of heavy applications of limestone seems to be due to the excessive production of nitrates brought about by heavy liming.

Inoculation of legumes reduces the amount of nitrates removed from the soil by the plants.

Limestone applied to soil in amounts only slightly in excess of that required to neutralize an acid soil may play an important part in nitrogen fixation by facilitating inoculation and the growth of tubercle organisms.

The efficiency of bone meal was greatly decreased by the application of ground limestone.

Ground limestone applied to the soil used in this experiment decreased the amount of water soluble phosphates in the soil.

The results seem to indicate that the depressing effect upon the growth of certain plants due to heavy applications of lime may be caused, at least in part, by a decrease in the amount of available phosphates in the soil due to the presence of lime.

Plate I Cowpeas after five weeks growth

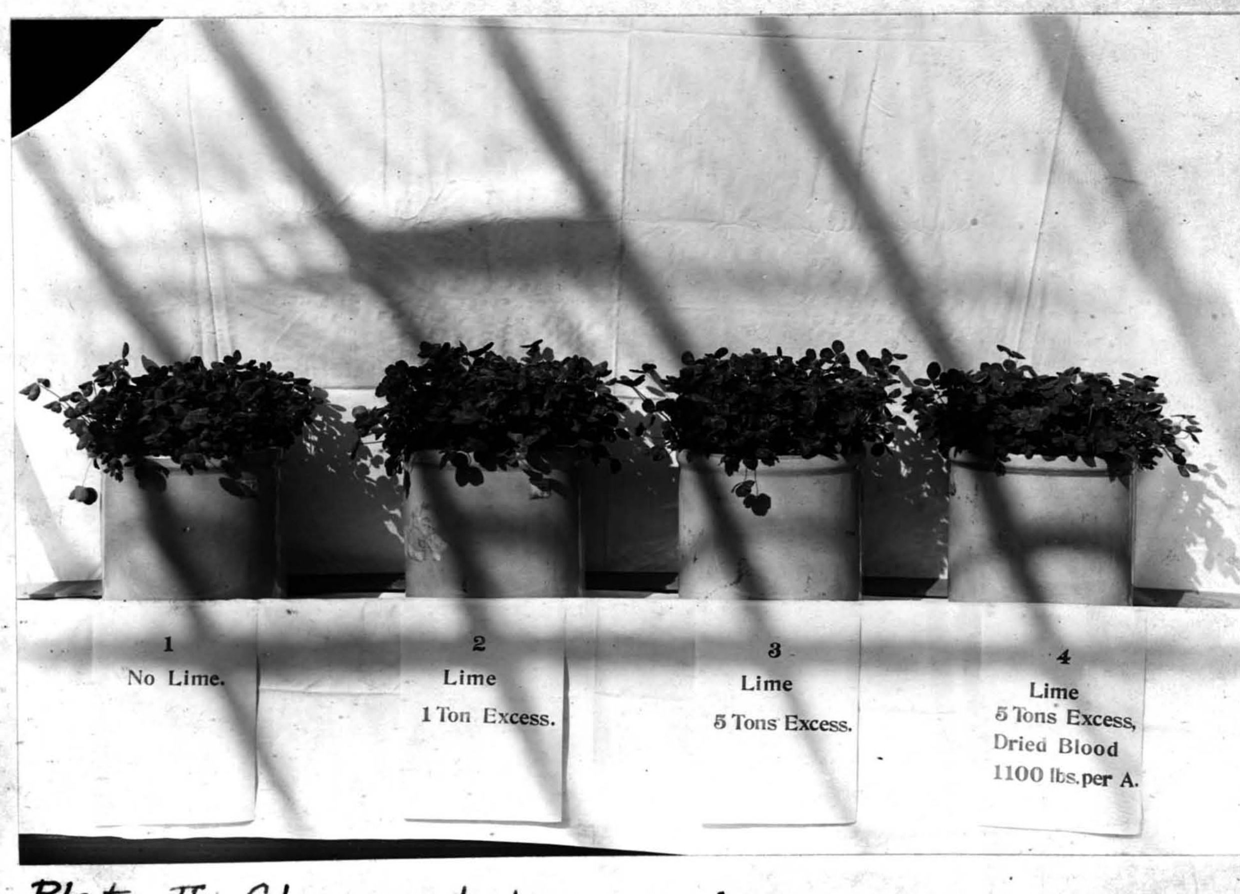


Plate II Clover at time of harvesting.

Plate III Soybeans. Series 3. at time of harvesting.

Plate IV Corn, Series 4, at time of harvesting.

Plat V Soy beans, Series 5, at time of harvesting.

Plate VI Roots of Inoculated and Uninoculated soy beans.

DUE	RETURNED
APR 22 1974	APR 9 1974
[illegible] 1974	MAY 7 1974
[illegible]	JUN 8 1977
DEC [illegible]	[illegible] 1978
MU MAR 15 2013	

Form 104