THE EFFECT OF VARIOUS FERTILITY TREATMENTS, INCLUDING PHOSPHORUS, CALCIUM, NITROGEN, AND SULFUR ON THE YIELD AND COMPOSITION OF ALFALFA GROWN ON BETHANY SILT LOAM

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INTRODUCTION

Soil tests made over a period of years at the Oklahoma Agricultural Experiment Station show that a little over seventy percent of the soils tested were low in available phosphorus (11)[1]. Harper (25,26) concluded that phosphorus was usually the first limiting factor in crop production on the prairie soils of central and eastern Oklahoma, and that many of these soils could not support a profitable agriculture without the addition of phosphate fertilizers. Murphy (38) has shown that the use of nitrogen and phosphate fertilizers increased wheat yields on Oklahoma soils. Moss (35) reported that on plots receiving annual applications of phosphorus fertilizer, yields were increased with each subsequent application.

With the phosphate fertilizer consumption in Oklahoma rising to an all time high of 38,765 tons of superphosphate and 14,106 tons of rock phosphate in the 1953-1954 season (60), the source and the cost of phosphorus fertilizers becomes an added production expense for Oklahoma farmers. It would be advantageous if the cheaper sources of phosphate could be used economically and effectively on some of the more responsive crops in the crop rotation.

In a system as complex as the soil, the soil characteristics, and the nutrients associated with it play an improtant part in the utilization of a fertilizer amendment by a plant. This relation of soil, fertilizer material, and plant opens enormous opportunity for productive research. The proposed objectives of this experiment were to study the effect of

[1]Numbers in parenthesis refer to literature cited in bibliography.

sulfur, nitrogen, and calcium carbonate on the utilization of rock phosphate as compared to superphosphate, and to observe the influence of top soil and subsoil placement of fertilizers on plants grown on an Oklahoma soil type collected from two widely separated locations.

REVIEW OF LITERATURE

Many agronomic studies have been undertaken to compare the value of rock phosphate to superphosphate. The results that have been obtained were dependent upon the soil in question, its fertility status, and the crop grown. Results have been reported that showed that in some investigations rock phosphate was superior to superphosphate (59), and in some instances inferior (4,8), while other reports show rock phosphate (33,20) equal to superphosphate. The experimental results probably differ because of the complexity of the factors affecting phosphorus utilization by plants.

One of the principal problems of phosphorus fertilization seems to be that the amount of fertilizer added as available phosphorus becomes unavailable to the plant within a relatively short time after application. Several investigators (14,34) have found that only one-tenth to one-half of the phosphorus added as available phosphate was used by the plant, while the remainder was "fixed" by the soil. The problem of the fixation of phosphate fertilizers is important economically, so considerable work has been done in an attempt to find out more about reversion of soluble fertilizers to more insoluble forms.

One factor that affects the uptake of phosphorus is the calcium status of the soil. Rock phosphate, for example, seems to be more effective on acid or slightly acid soils (4,50). Jones (28) reported that rock phosphate studies demonstrated that at a pH of five, 235 percent more phosphorus was taken up by plants than at a pH of 6.5. Cook (13) concluded that hydrogen saturated soils greatly increased the availability of rock phosphate to plants with a low calcium requirement, but did not affect crops with a high calcium requirement.

Graham (23) believed that acidity in the soil, created by plant roots and soil microorganisms, was one of the major factors responsible for processing phosphate and other mineral fragments to more available forms. McIntire (31) pointed out that when larger amounts of calcic compounds were present, the soil solution would dissolve them and in turn lose most of its capacity to dissolve tricalcium phosphate. McLean et al. (33) believed that rock phosphate needed acid to make it available to plants, but that too much acidity encouraged the solubility of iron and aluminum compounds which caused reversion of available phosphorus to unavailable forms.

The hydrogen ion activity of the soil is not quite so effective in altering the availability of superphosphate according to several investigators. Salter and Barnes (50) did not find satisfactory evidence to show any effect of soil reaction upon the availability of ordinary superphosphate. In partial agreement with these data was Neller (41), who found that the addition of enough lime to raise the pH from 5.61 to 6.76 had no significant effect on the yield of oats but that lime did have a significant effect upon the phosphorus content of the plant. Scarseth (51) found that when a soil was limed to a pH of 6.0 that a depression in plant growth occurred when available phosphorus was low but that an increase in yield was obtained when phosphorus was high. Hallock and Attoe (24), in agreement with other investigators (31,13,7), found an increase in phosphorus availability as a result of lime applications. Albrecht and Smith (1) found that saturation of the soil with calcium increased the amount of phosphorus taken up by plants. They believed that the increase in uptake, instead of being the effect of the soil acidity, per se, was a more complex process which involved a plant-soil-calcium interaction enabling the plant to take up more phosphorus.

Graham (23) also believed that factors other than pH alone were instrumental in phosphorus availability. He found that some soils of pH 5.0 responded well to rock phosphate while others of the same pH did not. He concluded that the availability of phosphorus was related to the relative driving energies of the different collodial systems in the soil. Graham, along with Marshall (29), believed that soil colloids with a high bonding energy for calcium and a low bonding energy for hydrogen, would exchange the hydrogen from the colloid with some of the calcium of the more insoluble calcium phosphates leaving a more soluble form of phosphate. The collodial systems arranged in order as effective weathering agents were Wyoming Bentonite clay, Putnam clay, Kaolinite clay, and humus.

Various investigators agree that the amount of phosphorus taken up is greatly affected by the plant itself (21,1). Vandecaveye (56) believed that in many cases a low percentage of nitrogen and phosphorus in the plant could be attributed to a low fertility level or a nutrient unbalance. Fried (21) found little difference in the availability of monocalcium phosphate to several plants tested, but found in general that legumes utilized rock phosphates better than the grasses. In agreement with other investigators (36,5) Cook (13) and Salter and Barnes (50) found that lime greatly affected phosphorus availability to plants normally low in calcium but did not generally affect phosphorus availability for plants high in calcium such as legumes. Blaser et al. (8) found that the phosphorus content of white clover varied quite markedly with different phosphorus fertilizers while California burr clover did not.

Copeland and Merkle (14) found that organic matter seemed to be an aid in decreasing fixation, although it seemed to be overshadowed by other factors that tended to mask the organic matter such as the lime status of the soil. These authors also found, in agreement with Weeks and Miller (59), that additions of manure lowered phosphorus fixation. They believed that manure must exert a protective effect upon the soil mineral colloids. Dun (18) found that the removal of organic matter resulted in an increased phosphorus adsorption by the soil colloid in an acid suspension. DeTurk (17) found that from thirty to seventy percent of the total phosphorus in the soil was in organic form and that this phosphorus became available to the plant upon decomposition of the organic matter. Garman, (22) working with Oklahoma soils, found fifteen to eighty-five percent of the soil phosphorus in an organic form, and that it was being utilized at a rate about equal to that of inorganic phosphates. Noll and Irvin (42) found that small applications of nitrate of soda did not increase yields with superphosphate, but did cause increased yields with rock phosphate. Volk (57) found that adding nitrogen in the form of ammonium sulfate with rock phosphate gave higher yields than when nitrogen was added as sodium nitrate. Aslander (3) pointed out that the tonnage of lime used in Sweden had fallen off forty percent in the last ten years while crop production had increased. This presents a problem of how to keep down the loss in available phosphorus.

There seems to be two general types of phosphorus fixation by the soil, chemical precipitation and adsorption. Bradfield et al. (10)

postulated three separate mechanisms that possibly overlap. They believed that at pH 2.0 to 5.0 the retention of phosphate was chiefly due to the gradual precipitation of phosphates by hydrated iron and aluminum oxides. At pH 4.5 to 7.5 phosphates were fixed on the surface of clay particles, and at pH 6.0 to 10.0 phosphorus was precipitated by divalent cations if present. Metzter (30) believed that the phosphorus fixing capacity of acid prairie soils could be largely accounted for by the precipitation phenomena, while fixation at particle surfaces was of slight practical significance. Cole et al. (12) obtained results indicating that at a high pH soluble phosphates were adsorbed as a monolayer on calcium carbonate surfaces and precipitated as dicalcium phosphate or a compound with similar solubility characteristics. McIntire (31) postulated that when superphosphate was added to an adequately limed or naturally calcarous soil the soluble phosphorus passed successively to dicalcium phosphate, tricalcium phosphate, and calcium fluorophosphate.

Several investigators (55,51,20) have found phosphate fixed by precipitation at low pH values as iron and aluminum phosphates. Dun (18) found that when free iron oxide was removed from experimental soils that there was a considerable decrease in phosphorus adsorption.

Moser (34) believed that phosphorus adsorption in acid soils was a resultant of adsorption by the clay particle or the formation of a silico-phospho-aluminum complex and the formation of crystalline iron aluminum hydrates where the phosphate ion replaced the hydroxyl ion within the crystal lattice. Murphy (37) doubted that fixation by iron and aluminum compounds accounted for all the phosphorus fixation in calcium saturated soils. He found that kaolinite clay had the ability to hold large quanities of phosphorus which was not readily available to the plant until a high degree of saturation was reached. He also found that kaolinite type clay had a greater capacity to adsorb phosphorus than montmorillonitic type clay.

Although properly inoculated legumes have the ability to assimilate atmospheric nitrogen, Hutcheson and McVickar (27) found that during the period of establishment, the small legume plants responded remarkably to small applications of nitrogen. In agreement with these findings were Bear and Wallace (6), who noted that while nitrogen fertilizer was of considerable value in establishing stands of alfalfa, topdressing of nitrogen fertilizer on established stands promoted the growth of weeds in the stand.

Alway (2) believed that sulfur was the most research slighted essential plant nutrient element. He believed, in agreement with the findings of other investigators (39,40,58,9), that there were several sulfur-deficient areas in the United States. Neller et al. (40) pointed out that sulfur deficiencies existed in arid as well as humid regions of the United States. Volk et al. (58) stated that, in manufacturing areas, enough sulfur probably came down in rainfall to supply crops; but in nonindustrial rural areas, this amount was quite small. Bledsoe and Blaser (9) found in Florida that while the soil had enough sulfur for grasses, it did not have a sufficient amount for plants high in protein such as clovers. They thought that the superiority of superphosphate over rock phosphate might possibly be due to the sulfur content of the superphosphate. Volk et al. (58) found that gypsum was about as efficient as elemental sulfur in increasing crop yields on sulfur deficient soils.

While most investigators have been concerned primarily with the surface soil; it is logical that, for deep rooted crops, a knowledge of the subsoil would be necessary. Several investigators (16,44) have found that there was a sizable variation in the amount and availability of phosphorus from soil to soil as well as from horizon to horizon. Stelly and Pierre (54) and Pearson et al. (44) found that although the percent of total phosphorus was fairly high in the surface soil, it decreased in the B horizon. The C horizon contained a higher percent of total phosphorus than the A horizon. The high phosphorus in the A horizon as compared to the B horizon was probably due to the accumulation by plants. Stelly and Pierre (54) found that in some soils the phosphorus in the lower horizons was highly available to crops while in other soils it was low. Pearson et al. (44) found, however, a higher percentage of available phosphorus in the C horizon than in the A horizon. Dennis and Chesnin (16) found a difference in availability of the phosphorus in the different horizons, but the order of availability varied from soil to soil. Pohlman (46) found that by liming the subsurface soil layer, that phosphorus was made more available and higher yields were obtained. In agreement with these findings were Romine and Metzger (47) who associated low pH with low phosphorus solubility, while Pearson et al. (44) found no consistent relation between pH and dilute acid soluble phosphorus of the soil.

Olsen et al. (43) pointed out that many agronomists have made strong contentions that soil series designations have little or no effect on the fertility status of soils. He found, though, that there was a close relation between soil series and pH, and between soil series and soluble phosphorus in fifteen major soil series in Nebraska ranging from fine sand to silty clay in texture. Smith (52) observed that the available phosphorus and pH test of the surface soil of two fields tested did not furnish a clue to an explanation of their different behavior toward rock phosphate. The soils of the two fields were of different soil associations and he suggested that the differences obtained might be attributed to the character of root growth as affected by the different permeability of the subsoil of the two soils.

Several investigators (17,20,32) have shown that the residual effect of rock phosphate lasts for several years. Weeks and Miller (59) found that rock phosphate exceeded superphosphate in residual effects in a field experiment. DeTurk (17) and McLean et al. (33) proposed the use of rock phosphate in conjunction with superphosphate to raise the phosphorus level of phosphorus deficient soils.

Investigations point out that phosphorus fertilizer is needed for maximum plant yields on many of the acid prairie soils of central and eastern Oklahoma. Superphosphate seems to be the predominant phosphorus fertilizer and although a considerable amount of rock phosphate is used, there seems to be some doubt as to the degree of its availability for plant growth. Only a part of the phosphorus fertilizer added to the soil as available phosphorus is used by the plant. The remainder is reverted to a more unavailable, or "fixed" form. The principal factor affecting the availability of phosphorus in these soils seems to be the lime status of the soil. A general agreement seems to be that lime aids in uptake of superphosphate, but that rock phosphate needs an acid or slightly acid soil for most economical use. Other factors, such as the type and amount of collodial material in the soil, the percent and activity of organic matter, and nutrient elements in the soil and added as fertilizers, have an effect on the phosphorus availability of the soil.

METHODS AND MATERIALS

The data included in this thesis are material obtained from a greenhouse study. The objective was to compare the relative value of fertilizer treatments, as indicated by plant yields and composition data, on two soils of the same soil type taken from two locations.

Description of the Soils Studied

The two soils used in this study were similar in profile characteristics and were classified as Bethany silt loam.[1] The sample sites were located approximately sixty miles apart, and the general soil association at each location was of considerable agronomic importance.

The sample referred to as "Soil A" was taken in northern Kay County, Oklahoma, SE 1/4 NE 1/4, Section 33, T 29 N, R 2 E. The area had been under continuous small grain production for at least fifteen years, and in cultivation for more than sixty years. Adjacent fields to the sample site had shown favorable response to phosphorus fertilization in the production of small grains and an increase in yield of legume crops was obtained when lime was added.[2]

The soil sample referred to as "Soil B" was taken from a check plot in the 5100 series on the Oklahoma Agricultural and Mechanical College Agronomy Farm, west of Stillwater, Payne County, Oklahoma. This soil was from a plot devoted to a four year rotational cropping system of cotton,

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[1]Profile descriptions furnished by H.M. Galloway, Assistant Soil Surveyor (Coop. U.S.D.A., and S.C.S.) and E.M. Templin, Soils Correlator; Oklahoma and Kansas. (Refer to Appendix)

[2]"Soil A" sample furnished by Dr. H.V. Eck, Agronomy Department, Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma.

small grains, darso, and clover. The rotation has been carried on since 1917. The top growth was removed each season. The soil samples were taken in May, 1954.

Preparation of Soils for Pot Culture

Each soil was divided into a topsoil and subsoil category. The soil labeled "topsoil" included all material from the surface to a sixteen inch depth. Samples referred to as "subsoil" were composites of material taken from the sixteen inch depth to thirty inches. Soil number "1" was a sample of topsoil taken from the Bethany silt loam (Soil A), and soil number "2" represents the subsoil. In the same order, soil number "3" was a sample taken from the topsoil of the Bethany silt loam (Soil B) and soil number "4" corresponds to the subsoil. Each soil was mixed thoroughly and sieved through a quarter-inch mesh screen and allowed to air dry, and then twelve pound increments of soil, 5,448 grams, were weighed into each pot and fertilizer treatments were made.

Laboratory Analyses of Soil Samples

A sufficient quantity of each soil was brought to the laboratory for analysis. The sample was air-dried and processed for analysis by crushing the aggregate with a metal roller and sieving through a twenty mesh screen. The results of the laboratory tests are included in Table I.

Determination of the soil texture was made by the Bouyoucos hydrometer method.[1]

The soil reaction value was read with a Beckman, glass electrode pH

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[1]Robert M. Reed, Soils Laboratory Manual, Agronomy Department, Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma.

TABLE I

SOIL CHARACTERISTICS DETERMINED BY LABORATORY ANALYSES

Tests	Soil #1	Soil #2	Soil #3	Soil #4
Mechanical Composition	58.7% sand 20.3% silt 21.0% clay	35.0% sand 28.0% silt 37.0% clay	55.0% sand 26.2% silt 18.8% clay	46.6% sand 20.6% silt 32.8% clay
Soil Reaction	pH 5.6	pH 6.0	pH 5.5	pH 5.9
Percent Organic Matter	1.72%	1.20%	1.14%	0.98%
Percent Total Nitrogen	0.1179%	0.0769%	0.0871%	0.0666%
Cation Exchange Capacity	18.82 m.e. per 100 gm.	31.48 m.e. per 100 gm.	15.63 m.e. per 100 gm	26.57 m.e. per 100 gm.
Total Exchangeable Bases	16.0 m.e. per 100 gm.	29.93 m.e. per 100 gm.	13.37 m.e. per 100 gm	22.63 m.e. per 100 gm.
Total Exchangeable Calcium	8.87 m.e. per 100 gm.	12.98 m.e. per 100 gm.	7.84 m.e. per 100 gm	12.25 m.e. per 100 gm.
Total Phosphorus Content	528 lbs. per acre	500 lbs. per acre	432 lbs. per acre	432 lbs. per acre
0.1 N. Acetic Acid Soluble Phosphorus	13.76 lbs. per acre	8.96 lbs. per acre	8.16 lbs. per acre	3.36 lbs. per acre

meter. A fifty gram sample of the soil was mixed with an equal weight of water and readings were taken after allowing sufficient time for equilibrium.

Organic matter content of the soil sample was measured indirectly by the "wet combustion process"[1] of organic carbon oxidation.

Total nitrogen in the soil material was determined by the Kjeldahl method of analysis.[2]

The cation exchange capacity of the soil was determined according to a method by Russell (48). The principle of the process involved filling the cation exchange positions on the clay with an ammonium ion by saturation of the soil with an ammonium acetate solution. The amount of the ammonium ion absorbed by the soil was determined by displacing it with magnesium oxide into excess standard acid. The acid neutralized was then ascertained by back titration.

An acetate leachate from the above analysis was used to establish the percent of total exchangeable bases. This procedure consisted of liberating the bases present by igniting the acetates, and determining the quantity of total bases by titration with standard acid.

The exchangeable calcium in milliequivalents per 100 grams of soil was found by precipitation of calcium as calcium oxalate from the ammonium acetate leachate, and oxidizing the oxalate with standard potassium permanganate.

Total phosphorus and acid-soluble phosphorus were determined colorimetrically.

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[1]H.J. Harper. Methods for the Analysis of Soil and Plant Material, Soils Laboratory, Oklahoma Agricultural and Mechanical College, 1948.

[2]Ibid.

Greenhouse Procedure

The soil was placed in two-gallon glazed, non-porous jars. The jars had been throughly washed and rinsed with distilled water, and the drain holes closed with rubber stoppers.

On September 28, 1954, plantings were made. Alfalfa seeds (Buffalo, variety) were placed approximately one-half inch below the soil surface in sufficient amount to insure the germination of fifteen seedlings. Thinning of the seedlings was delayed until ten good healthy plants could be selected and the effects of adverse greenhouse conditions could be minimized. After the pots were thinned of excess plants, they were arranged on the greenhouse bench in a randomized block-split plot design, and remained in the same arrangement throughout the experiment. On October 1, 1954, the soil in each pot was inoculated with Rhizobium bacteria culture, in order to reduce unequal activity of the nitrifying organisms that might affect the response of alfalfa on each soil. The bacterial culture was mixed with distilled water and a liberal supply of the inoculum was sprinkled directly on the soil surface.

Pots were irrigated with distilled water throughout the experiment. Sufficient water was added periodically to insure a favorable moisture condition for plant growth.

The first cutting was made on January 28 and 29, 1955, when the plants were approximately 1/3 in bloom. The plants were then thinned to eight plants per pot, and the successive cuttings were made at 1/10 bloom. The second cutting was made on March 12; the third on April 16; the fourth on May 25; the fifth on June 25; the sixth on July 23; the seventh on August 20, and the eighth cutting on October 3, 1955. The plants were clipped about one and one-half inches above the surface of the soil and autoclaved as soon as possible to stop metabolic activity. The plants were then dried at sixty degrees centigrade in a forced-air drying oven for 36 hours. The plants were weighed, and the yields obtained are reported in Table III. Next the dried plant material was ground in a micro mill until it would pass through a 40 mesh screen. The samples were then stored in small coin envelopes for analysis.

All yield and composition data were submitted to an analysis of variance according to the method of Snedecor (53), and soils and treatments were tested by the new multiple range test proposed by Duncan (19). The comparisons of sources of variation in plant yields and composition are reported in Tables IV,V,VII,VIII,X,XI,XIII,XIV,XVI,and XVII.

Soil Treatments

Fertilizer treatments were applied to the soil two days before the date of seeding. Lime was throughly mixed with all of the soil in the pots, while all other fertilizer materials were mixed with the top two inches of soil. Methods of combinations and rates of application of fertilizers are given in Table II.

Analytical reagent grade calcium carbonate was used as the liming material. It was added to the soil in an amount calculated to bring the calcium saturation of the soil to eighty percent of the total cation exchange capacity. Consequently, each soil required a different rate of calcium fertilization; however, this rate, once established, was used consistently throughout. All other calcium containing compounds, that were used in the treatments, were taken into consideration and adjustments were made as to the amount of calcium added.

TABLE II

FERTILIZER TREATMENTS ON SOILS IN GREENHOUSE POTS

Pot Numbers	Treatment	Rate Per Acre
1	None	
2	Calcium Carbonate	Soil 1 - 6,180 lbs. Soil 2 - 12,200 lbs. Soil 3 - 4,660 lbs. Soil 4 - 9,400 lbs.
3	Rock Phosphate	1,000 lbs.
4	Rock Phosphate Calcium Carbonate	1,000 lbs. (Specific to soil as in Treat. #2)
5	Rock Phosphate Calcium Sulfate	1,000 lbs. 225 lbs.
6	Rock Phosphate Calcium Sulfate Calcium Carbonate	1,000 lbs. 225 lbs. (Specific to soil as in Treat. #2)
7	Rock Phosphate Sulfur	1,000 lbs. 53 lbs.
8	Rock Phosphate Sulfur Calcium Carbonate	1,000 lbs. 53 lbs. (Specific to soil as in Treat. #2)
9	Rock Phosphate Ammonium Nitrate	1,000 lbs. 258 lbs.
10	Rock Phosphate Ammonium Nitrate Sulfur	1,000 lbs. 258 lbs. 53 lbs.
11	Rock Phosphate Ammonium Nitrate Sulfur Calcium Carbonate	1,000 lbs. 258 lbs. 53 lbs. (Specific to soil as in Treat. #2)
12	$Ca(H_2PO_4)_2$ [1] Calcium Sulfate[1]	293 lbs. 225 lbs.
13	$Ca(H_2PO_4)_2$ [1] Calcium Sulfate[1] Ammonium Nitrate	293 lbs. 225 lbs. 258 lbs.
14	$Ca(H_2PO_4)_2$ [1] Calcium Sulfate [1] Calcium Carbonate	293 lbs. 225 lbs. (Specific to soil as in Treat. #2)

[1]$Ca(H_2PO_4)_2$ and calcium sulfate in treatments 12, 13, and 14 are equivalent to 825 lbs. of superphosphate per acre.

Florida brown pebble phosphate, which contained thirty-three percent P_2O_5, provided material for the source of rock phosphate. To further reduce the granule size, this material was ball-milled, for three days, until the particles would pass through a two hundred mesh screen. Applications of 1,000 pounds per acre were consistent wherever rock phosphate additions were made. It was calculated that thirty-three percent of the rock phosphate added was P_2O_5. Assuming one-half of this to be available, then approximately one-hundred and sixty-five pounds of available P_2O_5 per acre was added to each pot. This assumption was based on data reported in the literature (49,5).

The treatment referred to as superphosphate was calculated as follows: Chemically pure analytical grade reagents, i.e., monobasic calcium phosphate,and calcium sulfate, were added in amounts equivalent to the mono calcium phosphate and gypsum that might be expected in an 825 pound per acre application of twenty percent superphosphate. Eight hundred and twenty-five pounds per acre of twenty percent superphosphate would furnish 165 pounds of P_2O_5 per acre, an amount corresponding to the assumed available phosphorus of rock phosphate.

For a nitrogen source, analytical grade ammonium nitrate was used. The nitrogen requirement was based on the assumption that a three tons per acre crop of alfalfa, containing 2.2 percent nitrogen, would contain one-hundred and thirty-two pounds of nitrogen. With the further assumption, that the plants of the first crop would take two-thirds, of their nitrogen from the soil, the nitrogen requirement would be 86 pounds per acre. This, in terms of ammonium nitrate, is 258 pounds per acre.

The amount of calcium sulfate, or "gypsum" supplement, was based upon the two-hundred and twenty-five pound per acre application that would be present in the superphosphate treatment. Analytical grade calcium sulfate provided the "gypsum" source for this treatment.

Elemental sulfur was applied at the rate calculated to correspond with the sulfur content of the gypsum treatment. On this basis, fifty-three pounds of sulfur per acre was equivalent to a two-hundred and twenty-five pound treatment of gypsum. A precipitated analytical grade of sulfur (flowers of sulfur) served as the source for this element.

Chemical Analyses of Plant Material

The total nitrogen in the plant material was determined by the Kjeldahl method. A one-half gram sample of plant forage was digested by sulfuric acid and selenium, the latter acting as a catalyzer. The solution was then made basic with concentrated sodium hydroxide; and the nitrogen, in the form of ammonia, was distilled into a receiving flask containing a standard acid. The solution was then titrated with standard sodium hydroxide using methyl red-methylene blue as an indicator. Total nitrogen was calculated by a conversion factor.

A colormetric procedure outlined by Harper[1] was used to determine the percent phosphorus. One-half gram samples of plant forage were digested in a solution, consisting of three parts concentrated nitric acid and one part seventy to seventy-two percent perchloric acid. After digestion, the samples were brought up to two-hundred milliliter volume with distilled water. Forty milliliter aliquots were withdrawn for

[1]H.J. Harper. Methods for the Analysis of Soil and Plant Material, Soils Laboratory, Oklahoma Agricultural and Mechanical College, 1948.

analysis. The presence of phosphorus was indicated by a blue color developed by the reducing action of hydrazine sulfate on a sodium molybdate-phosphate ion complex. The color density was determined from light adsorption readings on the Fisher electrophotometer. The readings obtained were converted into milligrams of phosphorus by comparsion with a standard curve.

The calcium and potassium were determined by running a small amount of sample, from the phosphorus digestion solution, through a Beckman model D U Flame Spectrophotometer with a photomultiplier attachment. The fuel gases were hydrogen and oxygen. The calcium spectrum was measured on a photomultiplier blue sensitive phototube using the calcium resonance line at 424.4 millimicrons. The potassium was run on a red sensitive photoelectric tube on the excited atom electronic line of 770 millimicrons. The readings were plotted against a standard curve and the amount of potassium and calcium calculated.

RESULTS AND DISCUSSION

The Yield of Alfalfa Forage

The Effect of Soils on Yields

The analysis of variance test, Table IV, indicates that the total yields for eight cuttings show no significant difference between Soil A and Soil B, and no significant difference between subsoil and topsoil. These results are different from Phibbs (45) work and effectively demonstrates that reliability of data from one harvest is questionable. It is concluded from this experiment that the soils from these two locations acted the same; and for the same phosphate fertilizer practice, the soils should respond equally. In other words, these two soils were probably the same soil insofar as the results of the experiment show.

The yield from the four soils, although no significance was noted at the 5 percent probability level, were not equal as shown in Table III. The topsoil of Soil A and the subsoil of Soil B were very close in total yield. The subsoil of Soil A and the topsoil of Soil B were fairly close together, and a little below the yield of the other two soils. The yield from Soil 4 (Subsoil of Soil B) was very low for the check and calcium carbonate treatment, while the check and calcium carbonate treatment of Soil A were fairly high. When the phosphorus and calcium carbonate treatment were added to Soil 4 however, the growth exceeded that of the similar treatment in Soil 1, thereby, making the total yield of this soil approximately the same as Soil 1. Part of the higher yields for Soil 4 might be attributed to the better physical condition of this soil. Phosphorus, apparently, was more of a limiting factor for this soil than for the other three soils, as indicated by Figure VI and Table III. This seems to bear

TABLE III

TOTAL WEIGHTS IN GRAMS OF EIGHT CUTTINGS OF ALFALFA FORAGE GROWN IN GREENHOUSE POTS

Treatments	Soil #1	Soil #2	Soil #3	Soil #4	Treatment Totals
1.	83.97	21.60	36.17	1.01	142.75
2.	110.65	50.43	80.37	8.47	249.92
3.	114.47	113.60	114.01	138.59	480.67
4.	122.55	136.06	122.10	122.34	503.05
5.	110.65	100.11	120.52	126.46	457.74
6.	128.30	135.62	121.77	146.66	532.35
7.	109.02	115.97	106.55	125.19	456.73
8.	132.61	143.29	132.89	122.46	531.25
9.	112.86	111.16	113.74	146.23	483.99
10.	112.50	134.54	107.88	140.04	494.96
11.	129.50	126.02	134.56	140.03	530.11
12.	108.72	94.63	107.90	126.01	437.26
13.	116.83	109.39	105.37	122.79	454.38
14.	131.87	174.58	127.70	156.75	590.90
TOTALS	1624.50	1567.00	1531.53	1623.03	6346.06

Fertilizer Treatments on Soils in Greenhouse Pots

Treat. No.	Treat.	Rate Per Acre In Lbs.
1.	Check	None
2.	$CaCO_3$	Soil 1- 6,180 Soil 2-12,200 Soil 3- 4,660 Soil 4- 9,400
3.	R.P.	1000
4.	R.P. $CaCO_3$	1000 *
5.	R.P. $CaSO_4$	1000 225
6.	R.P. $CaSO_4$ $CaCO_3$	1000 225 *
7.	R.P. S.	1000 53

Treat. No.	Treat.	Rate Per Acre In Lbs.
8.	R.P. S. $CaCO_3$	1000 53 *
9.	R.P. N.	1000 86
10.	R.P. N. S.	1000 86 53
11.	R.P. N. S. $CaCO_3$	1000 86 53 *
12.	S.P.	825
13.	S.P. N.	825 86
14.	S.P. $CaCO_3$	825 *

*$CaCO_3$ specific as to soil, as in treatment #2.

TABLE IV

ANALYSIS OF VARIANCE OF RANDOMIZED BLOCK SPLIT PLOT EXPERIMENT ON ALFALFA YIELDS[1]

Source of Variation	Degrees Freedom	Sum of Squares	Mean Squares	F. Term
Total	167	22,416.988		
Reps.	2	114.660	57.330	1.42
Soils	3	147.151	49.050	1.21
Soil A vs. Soil B		8.122	8.122	0.20
Topsoil vs. Subsoil		6.781	6.781	0.17
Main Plot Error	6	242.449	40.408	
Treatments:	13	15096.242	1161.249	62.739**
Check vs. $CaCO_3$		478.559	478.559	25.855**
$CaCO_3$ vs. No $CaCO_3$		1408.438	1408.438	76.095**
R.P. vs. S.P.		3.055	3.055	0.165[2]
S. Source vs. None		3.22	3.22	0.174
$CaSO_4$ vs. S.		.093	.093	0.005
N. vs. None		37.476	37.476	2.025
$CaSO_4$ vs. None		5.583	5.583	0.302
$CaCO_3$ x R.P.		149.778	149.778	8.092**[3]
$CaCO_3$ x S.P.		44.989	44.989	2.431
$CaCO_3$ + S.P. vs. S.P. Alone		983.552	983.552	53.165**
$CaCO_3$ + R.P. vs. R.P. Alone		20.869	20.869	1.117
Treatment x Soils	39	4891.553	125.424	6.776**
Experimental Error	104	1924.953	18.509	

**Denotes significance at a 1% probability level.

[1]Analysis of variance of the split plot design, showing the comparisons made, are in Table XVIII in the Appendix.

[2]Indicates that the second factor in the comparison is greater than the first.

[3]Indicates a depressive interaction.

TABLE V

A MULTIPLE RANGE TEST SHOWING SIGNIFICANT DIFFERENCE OF ALFALFA YIELDS DUE TO THE EFFECTS OF TREATMENTS

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = 1.242$

B. Shortest Significant Ranges: ($N_2 = 100$)

Range:	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(12)	(14)
(5% p-level) p =	2.80	2.95	3.05	3.12	3.18	3.22	3.26	3.29	3.32	3.36	3.40
R_p =	3.478	3.664	3.788	3.875	3.950	3.999	4.048	4.086	4.123	4.173	4.223

C. Results

Treatments:	1	2	12	13	7	5	3	9	10	4	11	8	6	14
Means Ranked In Order	11.90	20.83	36.44	37.87	38.06	38.15	40.06	40.33	41.25	41.93	44.18	44.27	44.36	49.24

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Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different. A broken line underscore indicates a similarity of treatments at a 5% p-level.

out the validity of the soil test data for available phosphorus in Table I.

The Effect of Treatments on Yield

The yield result totals, for eight cuttings of alfalfa forage for three replications, according to soil and treatment, and treatment totals for the four soils and three replications are reported in Table III. The rock phosphate treatment significantly increased yields over both the check and calcium carbonate treatments as shown in Figure VI. The multiple range test, Table V, shows no similarity between the check and calcium carbonate treatment or between these treatments and any other treatment. The addition of lime to rock phosphate did not significantly increase the yield at the 5 percent probability level as shown in the multiple range test, Table V. The F-term in Table IV shows a depressive interaction between rock phosphate and calcium carbonate. The addition of a sulfur source to rock phosphate increased yields slightly, but not enough for significance at the 5 percent probability level. The effect of calcium sulfate and calcium carbonate together, though, was enough to increase the yield at the 5 percent probability level over rock phosphate alone, as shown in the multiple range test, Table V. There was a very small F-term, comparing $CaSO_4$ treatment to sulfur, indicating very little difference between these treatments. The effects of sulfur sources on rock phosphate and other treatments are shown in Figure V and Figure III.

Phibbs (45) reported that nitrogen increased the yield over no nitrogen treatment at both probability levels for the first cutting. The total yield still showed an increase for the total of eight cuttings as shown in Table IV, and Figure V; although not enough for significance at the 5

Figure I. Alfalfa growth in greenhouse pots from soil A, topsoil, before the third cutting, showing the effect of, from left to right, treatments 1 through 7.

Figure II. Alfalfa growth in greenhouse pots from soil A, topsoil before the third cutting showing the effects of, from left to right, treatments 7 through 14.

Figure III. Alfalfa growth in greenhouse pots from soil A, topsoil, before the third cutting, showing the effects of no treatment, of 825 pounds per acre superphosphate treatment, 1000 pounds per acre rock phosphate treatment, alone and in combination with two different sources of sulfur.

Figure IV. Alfalfa growth in greenhouse pots from soil A, subsoil, before the third cutting, showing the effects of 825 pounds per acre of superphosphate and 1000 pounds per acre of rock phosphate, with and without calcium carbonate treatment, and 1000 pounds per acre of rock phosphate treatment with sulfur treatment, with and without calcium carbonate treatment.

Figure V. Alfalfa growth in greenhouse pots from soil B, subsoil, before the third cutting, showing the effects of 1000 pounds per acre rock phosphate treatment alone and in combination with calcium carbonate treatment, and in combination with nitrogen and sulfur with and without

Figure VI. Alfalfa growth in greenhouse pots from soil B, topsoil and subsoil, before the third cutting, showing the effects of no treatment, of calcium carbonate treatment, and of 1000 pounds per acre rock phosphate plus calcium carbonate treatment.

percent probability level.

There was no significant difference between the yields of rock phosphate and superphosphate. The addition of calcium carbonate to rock phosphate increased the yields only slightly. This increase was not enough for significance. The addition of calcium carbonate to superphosphate increased yields sufficiently for a highly significant F-term at both probability levels. The difference was enough to make this treatment greater than and different from all other treatments, as shown in the multiple range test, Table IV. The results of the above treatments are shown in Figure IV. Applications of sulfur increased the yield of rock phosphate slightly, but not enough for significance. The nitrogen treatment as reported on rock phosphate increased yields slightly but not enough for significance.

The multiple range test, Table V, indicates that superphosphate treatments were not quite as effective as rock phosphate on these soils, unless calcium carbonate was added to the superphosphate. The check treatment, the calcium carbonate treatment, and the superphosphate plus calcium carbonate treatment were not similar to each other or to any of the other treatments. Relative response of all treatments on Soil A topsoil are shown in Figures I and II.

The results seem to agree with the original premise that the phosphorus in rock phosphate is fifty percent available to alfalfa. As far as yields are concerned, there was no significant difference between the rock phosphate and superphosphate treatments when one assumes that fifty percent of the phosphorus in rock phosphate is available (at least under the conditions imposed by this experiment).

The Phosphorus Composition of Alfalfa Forage

The Effect of Soils on Phosphorus Composition

The analysis of variance table for phosphorus, Table VII, shows that the four soils were important factors contributing to significant differences in phosphorus composition of plant material. The total amounts of phosphorus taken up by the alfalfa are listed in Table VI. Soil B was significantly higher than Soil A at the 1 percent probability level as to total phosphorus uptake; and the topsoils of Soil A and Soil B were significantly higher than the subsoils of these two soils at the 1 percent probability level. The soils ranked in order of amount of phosphorus taken up were as follows: Soil #3 (3.101 grs. of P.), Soil #1 (2.985 grs. of P.), Soil #4 (2.856 grs. of P.), and Soil #2 (2.501 grs. of P.). This was the same order found by Phibbs (45) for the first cutting. Although the amount of phosphorus taken up would be dependent upon the weight of harvest, there appears to be no correlation between yields (of which there was no significant difference at the 5 percent probability level) and the amount of phosphorus taken up.

The Effect of Treatments on Phosphorus Composition

When treatments were considered as a source of variation of phosphorus composition, the multiple range test, Table VIII, shows that at the 5 percent probability level, the check treatment and calcium carbonate treatment were not similar to each other or to any other treatment. Treatment number 14 (superphosphate and calcium carbonate) was significantly higher at the 5 percent probability level than any other treatment. All of the rock phosphate treatments receiving calcium carbonate are grouped together at the lower end of the multiple range test, Table VIII, just above the

TABLE VI

TOTAL WEIGHTS OF PHOSPHORUS IN GRAMS TAKEN UP BY SIX[1] CUTTINGS OF ALFALFA FORAGE GROWN IN GREENHOUSE POTS

Treatments	Soil #1	Soil #2	Soil #3	Soil #4	Treatment Totals
1.	.11077	.02893	.05435		.19405
2.	.15615	.05756	.10225	.00711	.32307
3.	.22875	.21366	.24944	.24686	.93871
4.	.19704	.16508	.21406	.17046	.74654
5.	.22365	.17518	.25966	.25683	.91532
6.	.21264	.17554	.20728	.18124	.77670
7.	.21858	.19494	.24716	.27051	.93475
8.	.21430	.18381	.25349	.21448	.86608
9.	.23401	.20767	.25749	.27049	.96966
10.	.22897	.23110	.24019	.27956	.97982
11.	.19163	.16849	.24628	.21341	.81981
12.	.23430	.18637	.25439	.23833	.91339
13.	.24141	.20745	.22220	.24217	.91323
14.	.28915	.30520	.29294	.26422	1.15151
TOTALS	2.98491	2.50098	3.10118	2.85557	11.44264

Fertilizer Treatments on Soils in Greenhouse Pots

Treat. No.	Treat.	Rate Per Acre In Lbs.
1.	Check	None
2.	$CaCO_3$	Soil 1- 6,180 Soil 2-12,200 Soil 3- 4,660 Soil 4- 9,400
3.	R.P.	1000
4.	R.P. $CaCO_3$	1000 *
5.	R.P. $CaSO_4$	1000 225
6.	R.P. $CaSO_4$ $CaCO_3$	1000 225 *
7.	R.P. S.	1000 53

Treat. No.	Treat.	Rate Per Acre In Lbs.
8.	R.P. S. $CaCO_3$	1000 53 *
9.	R.P. N.	1000 86
10.	R.P. N. S.	1000 86 53
11.	R.P. N. S. $CaCO_3$	1000 86 53 *
12.	S.P.	825
13.	S.P. N.	825 86
14.	S.P. $CaCO_3$	825 *

*$CaCO_3$ specific as to soil, as in treatment #2.
[1]Cuttings one through six were analyzed for phosphorus.

TABLE VII

ANALYSIS OF VARIANCE OF RANDOMIZED BLOCK SPLIT PLOT EXPERIMENT ON PHOSPHORUS COMPOSITION OF ALFALFA FORAGE

Source of Variation	Degrees Freedom	Sum of Squares	Mean Squares	F. Term
Total	167	.09736		
Reps.	2	.00044	.00022	1.538
Soils	3	.00482	.00160	11.189**
Soil A vs. Soil B		.00131	.00131	9.161**[1]
Topsoil vs. Subsoil		.00316	.00316	22.098**
Main Plot Error	6	.00086	.000143	
Treatments:	13	.07163	.00551	55.826**
Check vs. $CaCO_3$		.00119	.00119	12.057**
$CaCO_3$ vs. None		.000257	.000257	2.604[1]
R.P. vs. S.P.		.00145	.00145	14.691**[1]
S. Source vs. None		.000220	.000220	2.229
$CaSO_4$ vs. S.		.000001	.000001	.010
N. vs. None		.000009	.000009	.091
$CaSO_4$ vs. None		.000141	.000141	1.429
$CaCO_3$ x R.P.		.00215	.00215	21.783**[2]
$CaCO_3$ x S.P.		.000248	.000248	2.513
$CaCO_3$ + S.P. vs. S.P. Alone		.00236	.00236	23.911**
$CaCO_3$ + R.P. vs. R.P. Alone		.00154	.00154	15.603**[1]
Treatment x Soils	39	.00934	.000239	2.42**
Experimental Error	104	.01027	.0000987	

**Denotes significance at a 1% probability level.

[1]Indicates that the second factor in the comparison is greater than the first.

[2]Indicates depressive interaction.

TABLE VIII

A MULTIPLE RANGE TEST SHOWING THE SIGNIFICANT DIFFERENCES OF PHOSPHORUS UPTAKE DUE TO THE EFFECT OF TREATMENT

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}}$ = .002828

B. Shortest Significant Ranges: (N_2 = 100)

Range:	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(12)	(14)
(5% p-level) p =	2.80	2.95	3.05	3.12	3.18	3.22	3.26	3.29	3.32	3.36	3.40
R_p =	.00792	.00834	.00863	.00882	.00899	.00911	.00922	.00930	.00939	.00950	.00962

C. Results

Treatments:	1	2	4	6	11	8	13	12	5	7	3	9	10	14
Means Ranked In Order	.0162	.0269	.0622	.0647	.0683	.0722	.0761	.0761	.0763	.0779	.0782	.0808	.0817	.0960

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Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different. A broken line underscore indicates a similarity of treatments at a 5% p-level.

check and calcium carbonate treatment. Treatments 6, 8, and 11 are similar to each other, as well as to some of the higher ranking treatments, while treatment 4 is not similar to treatment 8. All rock phosphate treatments not receiving calcium carbonate and the two superphosphate treatments not receiving calcium carbonate are grouped together and are similar to each other at the 5 percent probability level. This perhaps indicates a depressive effect of calcium carbonate on the availability of the phosphorus in rock phosphate. This supposition is substantiated by Table VII, which shows a depressive interaction between rock phosphate and calcium carbonate at the 1 percent probability level, and the comparison showing that the rock phosphate treatment alone took up significantly more phosphorus at the 1 percent probability level than the rock phosphate plus calcium carbonate treatment. Although there was not a significant interaction between calcium carbonate and superphosphate, calcium carbonate plus superphosphate, did increase the total phosphorus uptake significantly at the 1 percent probability level as shown in Table VII.

Apparently nitrogen increased the uptake of phosphorus slightly, but not nearly enough for significance. There was some increase in phosphorus due to sulfur source, although still not sufficient increase for significance. Superphosphate was significantly higher at the 1 percent probability level in increasing the uptake of phosphorus by the plant than rock phosphate as shown in Table VII. A considerable amount of this significance could be attributed to the increase of phosphorus uptake by the addition of calcium carbonate to the superphosphate. The rock phosphate treatments without calcium carbonate were all slightly higher (although not enough for significance) than the superphosphate treatments without calcium carbonate. This is in agreement with the findings of Graham (23), who found that he decreased the phosphorus content of plants by adding calcium carbonate to rock phosphate. Apparently the increased calcium content of the soil causes a decreased rate of breakdown of rock phosphate, while superphosphate is apparently made more available as shown in Table VII.

Superphosphate materially increased the phosphorus content of the alfalfa plants and rock phosphate also increased the phosphorus content, but not as much as superphosphate where calcium carbonate was present. Where calcium carbonate was present with rock phosphate there was a drastic reduction in the phosphorus content of the plant.

The Potassium Composition of Alfalfa Forage

The Effects of Soils on Potassium Composition

The analysis of variance table for potassium, Table X, shows a significant difference at the 1 percent probability level between Soil A and Soil B insofar as potassium uptake was concerned. There was no significant difference between the topsoil of Soil A and Soil B and the subsoil of these two soils. The total potassium uptake for the four soils were as follows: Soil #2 (14.764 grs. of K.), Soil #3 (14.016 grs. of K.), Soil #1 (12.063 grs. of K.), and Soil #4 (11.207 grs. of K.). The topsoil of Soil A outyielded the topsoil of Soil B, and the subsoil of Soil A outyielded the subsoil of Soil B, making a significant difference in potassium uptake between Soil A and Soil B. The order of potassium uptake for the soils was 2,3,1,4, which was the reverse order of the soils for for calcium uptake which was 4,1,3,2. This seems to indicate that

TABLE IX

TOTAL WEIGHTS OF POTASSIUM IN GRAMS TAKEN UP BY FIVE[1] CUTTINGS OF ALFALFA FORAGE GROWN IN GREENHOUSE POTS

Treatments	Soil #1	Soil #2	Soil #3	Soil #4	Treatment Totals
1.	.71685	.31589	.52908	.01336	1.57518
2.	.86699	.70376	.81422	.13125	2.51622
3.	.91061	1.15072	1.18981	.72312	3.97426
4.	.73001	1.31223	1.00095	.92505	3.96924
5.	.93901	.93434	1.07469	.91685	3.86489
6.	.96690	1.23588	.97117	1.11134	4.28529
7.	.90125	1.02862	1.02198	.82206	3.77391
8.	.85224	1.36134	1.17359	.86965	4.25682
9.	.90126	1.03920	1.06316	.90351	3.90713
10.	.86494	1.19428	1.04660	.93192	4.03774
11.	.83042	1.11473	1.06316	.96112	3.96943
12.	.87357	.89074	1.02485	.93130	3.72046
13.	.92871	1.00037	.91526	.95145	3.79579
14.	.77976	1.48225	1.12774	1.01367	4.40342
TOTALS	12.06252	14.76435	14.01626	11.20665	52.04978

Fertilizer Treatments on Soils in Greenhouse Pots

Treat. No.	Treat.	Rate Per Acre In Lbs.
1.	Check	None
2.	$CaCO_3$	Soil 1- 6,180 Soil 2-12,200 Soil 3- 4,660 Soil 4- 9,400
3.	R.P.	1000
4.	R.P. $CaCO_3$	1000 *
5.	R.P. $CaSO_4$	1000 225
6.	R.P. $CaSO_4$ $CaCO_3$	1000 225 *
7.	R.P. S.	1000 53
8.	R.P. S. $CaCO_3$	1000 53 *
9.	R.P. N.	1000 86
10.	R.P. N. S.	1000 86 53
11.	R.P. N. S. $CaCO_3$	1000 86 53 *
12.	S.P.	825
13.	S.P. N.	825 86
14.	S.P. $CaCO_3$	825 *

*$CaCO_3$ specific as to soil, as in treatment #2.

[1]Cuttings two through six were analyzed for potassium.

TABLE X

ANALYSIS OF VARIANCE OF RANDOMIZED BLOCK SPLIT PLOT EXPERIMENT ON POTASSIUM COMPOSITION OF ALFALFA FORAGE

Source of Variation	Degrees Freedom	Sum of Squares	Mean Square	F. Term
Total	167	1.42143		
Reps.	2	.00540	.00270	1.735
Soils	3	.19620	.06540	42.0308**
Soil A vs. Soil B		.01531	.01531	9.8393**
Topsoil vs. Subsoil		.00008	.00008	.0514
Main Plot Error	6	.00934	.001556	
Treatments:	13	.62323	.04794	20.487**
Check vs. $CaCO_3$		.03690	.03690	15.769**
$CaCO_3$ vs. None		.04182	.04182	17.872**
R.P. vs. S.P.		.000066	.000066	.028[1]
S. Source vs. None		.00066	.00066	.282
$CaSO_4$ vs. S.		.00030	.00030	.128
N. vs. None		.00000	.00000	.000
$CaSO_4$ vs. None		.00089	.00089	.380
$CaCO_3$ x R.P.		.01865	.01865	7.9700**[2]
$CaCO_3$ x S.P.		.01387	.01387	5.927*[2]
$CaCO_3$ + S.P. vs. S.P. Alone		.01943	.01943	8.265**
$CaCO_3$ + R.P. vs. R.P. Alone		.00000	.00000	.000
Treatments x Soils	39	.34385	.008816	3.767**
Experimental Error	104	.24341	.00234	

*Denotes significance at a 5% probability level.
**Denotes significance at a 1% probability level.

[1]Indicates that the second factor in the comparison is greater than the first.

[2]Indicates depressive interaction.

TABLE XI

A MULTIPLE RANGE TEST SHOWING THE SIGNIFICANT DIFFERENCES OF POTASSIUM UPTAKE DUE TO THE EFFECT OF TREATMENT

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .00441$

B. Shortest Significant Ranges: ($N_2 = 100$)

Range:	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(12)	(14)
(5% p-level) p =	2.80	2.95	3.05	3.12	3.18	3.22	3.26	3.29	3.32	3.36	3.40
R_p =	.01235	.01301	.01345	.01376	.01402	.01420	.01438	.01451	.01464	.01482	.01499

C. Results

Treatments:	1	2	12	7	13	5	9	4	11	3	10	8	6	14
Means Ranked In Order	.1313	.2097	.3100	.3145	.3163	.3221	.3256	.3308	.3308	.3312	.3365	.3547	.3571	.3670
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Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different. A broken line underscore indicates a similarity of treatments at a 5% p-level.

although both of these elements are necessary in sufficient amounts for proper plant growth, an excess of one lowers the amount of the other in the plant material.

The Effect of Treatments on Potassium Content

When treatments were considered as a source of variation of potassium composition, the multiple range test, Table XI, shows that at the 5 percent probability level, the check treatment and calcium carbonate treatment were not similar to each other or to any other treatment. Potassium was not added as a fertilizer amendment as it did not appear to be a limiting factor on these soils, and the results apparently bear this out. At the top of the multiple range test, Table XI, and similar to each other but to no other treatments are three treatments all having phosphorus, calcium carbonate, and a sulfur source in common. A sulfur source was added to treatments 8 and 6 while the superphosphate contained sulfur. Several other treatments are similar on this test but none seem to have common fertilizer amendments. As can be seen from the treatment totals, both rock phosphate and superphosphate increased the amount of potassium taken up. This was at least partly due to the increase in yield due to phosphorus treatment. There was no significant difference at the 5 percent probability level between rock phosphate and superphosphate in effecting the uptake of potassium taken up but, here too, this might have been a function of increased yield.

The rock phosphate plus calcium carbonate treatment shows a negative interaction at the 1 percent probability level and no significant increase in potassium uptake was obtained by adding calcium carbonate to rock phosphate. A depressive interaction was shown for superphosphate plus calcium carbonate treatment at the 5 percent probability level, although the addition of calcium carbonate to superphosphate increased the uptake of potassium at the 1 percent probability level. No significant increase in potassium uptake was indicated by the addition of a sulfur source or nitrogen treatment as shown in the analysis of variance test, Table X. Apparently, though, some sort of benefit seems to come from adding calcium carbonate and sulfur together, as shown in the multiple range test, Table XI, where the three treatments receiving phosphorus, calcium carbonate, and a sulfur source were significantly higher at the 5 percent probability level than any other treatments. The percent potassium was higher on the check treatment than on the calcium carbonate treatment although the total potassium taken up was higher for the calcium carbonate treatment. There was a significant increase in potassium uptake at the 1 percent probability level when comparing the limed pot vs. the unlimed pot. Part of the increased potassium uptake could be attributed to yield, but not entirely because several of the yields were just as high without as with calcium carbonate treatments.

In summation, phosphorus increases the amount of potassium taken up with little difference as to the two sources of phosphorus tested here. The amount of potassium was increased appreciably by treatments containing calcium carbonate. The exchangeable potassium in these two soils was supposedly high enough for normal plant growth, but the availability of potassium and the amount of potassium taken up were changed appreciably by treatments added to the soil.

The Calcium Composition of Alfalfa Forage

<u>The Effect of Soils on Calcium Composition</u>

TABLE XII

TOTAL WEIGHTS OF CALCIUM IN GRAMS TAKEN UP BY FIVE[1] CUTTINGS OF ALFALFA FORAGE GROWN IN GREENHOUSE POTS

Treatments	Soil #1	Soil #2	Soil #3	Soil #4	Treatment Totals
1.	.9101	.1521	.3120	.0116	1.3858
2.	1.1901	.6635	.8730	.0860	2.8126
3.	1.2985	1.0311	1.1734	1.7547	5.2577
4.	1.4632	1.5351	1.4964	1.9297	6.4244
5.	1.1103	.8196	1.2146	1.5048	4.6493
6.	1.7204	1.4947	1.5280	2.3662	7.1093
7.	1.1120	.9408	1.5710	1.5093	5.1331
8.	1.4610	1.7581	1.6131	2.1664	6.9986
9	1.2166	1.1249	1.2551	1.6810	5.2776
10.	1.2095	1.2574	1.2411	1.5167	5.2247
11.	1.4809	1.3275	1.5483	2.1151	6.4718
12.	1.0794	.8261	1.0288	1.4170	4.3513
13.	1.1314	1.3297	1.0592	1.3272	4.8475
14.	1.3653	1.8766	1.5835	1.9303	6.7557
TOTALS	17.7487	16.1372	17.4975	21.3160	72.6994

Fertilizer Treatments on Soils in Greenhouse Pots

Treat. No.	Treat.	Rate Per Acre In Lbs.
1.	Check	None
2.	$CaCO_3$	Soil 1- 6,180 Soil 2-12,200 Soil 3- 4,660 Soil 4- 9,400
3.	R.P.	1000
4.	R.P. $CaCO_3$	1000 *
5.	R.P. $CaSO_4$	1000 225
6.	R.P. $CaSO_4$ $CaCO_3$	1000 225 *
7.	R.P. S.	1000 53

Treat. No.	Treat.	Rate Per Acre In Lbs.
8.	R.P. S. $CaCO_3$	1000 53 *
9.	R.P. N.	1000 86
10.	R.P. N. S.	1000 86 53
11.	R.P. N. S. $CaCO_3$	1000 86 53 *
12.	S.P.	825
13.	S.P. N.	825 86
14.	S.P. $CaCO_3$	825 *

*$CaCO_3$ specific as to soil, as in treatment #2.

[1]Cuttings two through six were analyzed for calcium.

TABLE XIII

ANALYSIS OF VARIANCE OF RANDOMIZED BLOCK SPLIT PLOT EXPERIMENT ON CALCIUM COMPOSITION OF ALFALFA FORAGE

Source of Variation	Degrees Freedom	Sum of Squares	Mean Square	F. Term
Total	167	5.1623		
Reps.	2	0.0426	.0213	1.511
Soils	3	0.3491	.1164	8.255**
Soil A vs. Soil B		.1446	.1446	10.255**
Topsoil vs. Subsoil		.0290	.0290	2.057
Main Plot Error	6	.0848	.0141	
Treatments:	13	2.8189	.2168	24.636**
Check vs. $CaCO_3$		.0848	.0848	9.636**
$CaCO_3$ vs. None		.7759	.7759	88.170**
R.P. vs. S.P.		.0140	.0140	1.591
S. Source vs. None		.0022	.0022	.250
$CaSO_4$ vs. S.		.0029	.0029	.329[1]
N. vs. None		.0001	.0001	.011
$CaSO_4$ vs. None		.0027	.0027	.307[1]
$CaCO_3$ x R.P.		.0014	.0014	.159[2]
$CaCO_3$ x S.P.		.0199	.0199	2.261
$CaCO_3$ + S.P. vs. S.P. Alone		.2408	.2408	27.364**
$CaCO_3$ + R.P. vs. R.P. Alone		.0567	.0567	6.443*
Treatment x Soils	39	.9469	.0243	2.761**
Experimental Error	104	.9200	.0088	

*Denotes significance at a 5% probability level.
**Denotes significance at a 1% probability level.
[1]Indicates that the second factor in the comparison is greater than the first.
[2]Indicates depressive interaction.

TABLE XIV

A MULTIPLE RANGE TEST SHOWING THE SIGNIFICANT DIFFERENCES OF CALCIUM UPTAKE DUE TO THE EFFECT OF TREATMENT

A. Standard Error of Mean: $\sqrt{\dfrac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .027$

B. Shortest Significant Ranges: (N_2 = 100)

Range:	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(12)	(14)
(5% p-level) p =	2.80	2.95	3.05	3.12	3.18	3.22	3.26	3.29	3.32	3.36	3.40
R_p =	.0756	.0797	.0824	.0842	.0859	.0869	.0880	.0888	.0896	.0907	.0918

C. Results

Treatments:	1	2	12	5	13	7	10	3	9	4	11	14	8	6
Means Ranked In Order	.1155	.2344	.3626	.3874	.4040	.4278	.4354	.4381	.4398	.5354	.5393	.5630	.5832	.5924
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Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different. A broken line underscore indicates a similarity of treatments at a 5% p-level.

The analysis of variance test for calcium composition, Table XIII, shows a significant difference at the 1 percent probability level between Soil A and Soil B insofar as calcium uptake was concerned. There was no significance between the topsoils of Soil A and Soil B and the subsoil of these two soils. The yields from the four soils were different from each other and were as follows Soil #4 (21.3160 grs. of Ca.), Soil #1 (17.7487 grs. of Ca.), Soil #3 (17.4975 grs. of Ca.), and Soil #2 (16.1372 grs. of Ca.). As can be seen from these data, the amounts of calcium uptake from the topsoils were close together while the uptake from the subsoil of Soil B (Soil #4) was considerably higher than that from Soil A (Soil #2). The principal factor in the significance of Soil B over Soil A was due to the subsoil of Soil B outyielding the subsoil of Soil A. It is interesting to note that the order of the soils for calcium uptake, 4,1,3,2, was in reverse order of that of potassium which was 2,3,1,4. No similar relationship seems to exist between calcium or potassium and phosphorus. On yields and nitrogen uptake, the soils were not significantly different from each other.

The Effect of Treatments on Calcium Composition

When treatments were considered as a source of variation of calcium composition, the multiple range test, Table XIV, shows that at the 5 percent probability level, the check and calcium carbonate treatment were not similar to each other or to any other treatment. Grouped together at the high end of the test, and similar to each other at the 5 percent probability level, were the five treatments receiving calcium carbonate treatment plus a source of phosphorus. Grouped together below this group but above the check and calcium carbonate treatment were the seven treatments receiving a source of phosphorus but no calcium.

The analysis of variance test, Table XIII, shows that the calcium carbonate treatment significantly increased the calcium taken up over the check treatment at the 1 percent probability level. Calcium carbonate treatment vs. no calcium carbonate treatment on all the pots tested gave a very high F-term indicating a high significance of the calcium carbonate over no calcium carbonate in increasing calcium uptake. Part of the calcium uptake increase can no doubt be attributed to increased yields; but not all, because calcium carbonate did not increase the yield on all treatments. The analysis of variance table for potassium shows that there was no significant difference between the rock phosphate and superphosphate treatments in increasing calcium uptake. There was no significant effect of nitrogen or sulfur source upon the uptake of calcium. There was no significant interaction between calcium carbonate and either rock phosphate or superphosphate. The F-term for superphosphate times calcium carbonate was higher than for rock phosphate times calcium carbonate. Calcium carbonate plus superphosphate vs. superphosphate alone showed a significant increase at the 1 percent probability level. The rock phosphate plus calcium carbonate vs. rock phosphate alone increased calcium uptake at the 5 percent probability level, but was not as effective as the calcium carbonate plus superphosphate.

Phosphorus materially increased the amount of calcium taken up by the plants with no significant difference between rock phosphate and superphosphate. Calcium carbonate applications increased the amount of calcium taken up due both to yield and added amount of calcium in the plant.

The Nitrogen Composition of Alfalfa Forage

The Effect of Soils on Nitrogen Composition

The analysis of variance test, Table XV, shows a significant difference at the 5 percent probability level between soils in nitrogen uptake. There was no difference, however, between Soil A and Soil B, or between topsoil and subsoil. The nitrogen uptake from the four soils are reported in Table XV. The soils ranked according to yield are soil 4, soil 1, soil 2, and soil 3. This was not the order found by Phibbs (45) for nitrogen percentage for the first cutting, who found that the nitrogen percentage was in reverse order of the soils ranked according to yield. This may be interpreted to mean that the increase of one soil over another might be due to an increase in yield and not an increased nitrogen content on a percentage basis within the plant.

The Effect of Treatments on Nitrogen Composition

The effects of treatments on nitrogen composition as shown in the multiple range test, Table XVII, show that the check and calcium carbonate treatments were not similar to each other or to any other treatment. The highest amount of nitrogen uptake was on the superphosphate plus calcium carbonate treatment which was not similar to any other treatment. The nitrogen treatments did not significantly increase the amount of nitrogen taken up at the 5 percent probability level, although there was an increase evident after eight cuttings, Table XVI. The calcium carbonate treatment increased nitrogen uptake at the 1 percent probability level both on the calcium carbonate over the check treatment and the pots receiving calcium carbonate treatment vs. no calcium carbonate treatment, Table XVI. Both phosphate sources increased the amount of nitrogen taken

TABLE XV

TOTAL WEIGHTS OF NITROGEN IN GRAMS TAKEN UP BY SIX[1] CUTTINGS OF ALFALFA FORAGE GROWN IN GREENHOUSE POTS

Treatments	Soil #1	Soil #2	Soil #3	Soil #4	Treatment Totals
1.	2.0967	.5356	.8514	.0221	3.4968
2.	2.6677	1.1472	1.8258	1.2864	5.8122
3.	2.9192	3.0002	3.0021	3.7782	12.6997
4.	2.9112	3.1360	2.9793	2.8509	11.9134
5.	2.8356	2.6300	3.1000	3.5295	12.0951
6.	3.0102	3.1347	2.9880	3.5144	12.6473
7.	2.8632	2.9871	2.7543	3.5972	12.2018
8.	3.1571	3.3542	3.2613	2.8800	12.6526
9.	2.9311	3.0062	2.9723	3.7260	12.6356
10.	2.8418	3.2043	2.8193	3.7758	12.6412
11.	3.0460	3.0577	3.3091	3.5178	12.9306
12.	2.7023	2.6334	2.7966	3.4487	11.5810
13.	3.0087	3.0360	2.7591	3.5687	12.3725
14.	3.4753	4.4378	3.3035	4.1025	15.3191
TOTALS	40.4571	39.3364	38.7221	42.4833	160.9989

Fertilizer Treatments on Soils in Greenhouse Pots

Treat. No.	Treat.	Rate Per Acre In Lbs.
1.	Check	None
2.	$CaCO_3$	Soil 1- 6,180 Soil 2-12,200 Soil 3- 4,660 Soil 4- 9,400
3.	R.P.	1000
4.	R.P. $CaCO_3$	1000 *
5.	R.P. $CaSO_4$	1000 225
6.	R.P. $CaSO_4$ $CaCO_3$	1000 225 *
7.	R.P. S.	1000 53

Treat. No.	Treat.	Rate Per Acre In Lbs.
8.	R.P. S. $CaCO_3$	1000 53 *
9.	R.P. N.	1000 86
10.	R.P. N. S.	1000 86 53
11.	R.P. N. S. $CaCO_3$	1000 86 53 *
12.	S.P.	825
13.	S.P. N.	825 86
14.	S.P. $CaCO_3$	825 *

*$CaCO_3$ specific as to soil, as in treatment #2.
[1]Cuttings one through six were analyzed for nitrogen.

TABLE XVI

ANALYSIS OF VARIANCE OF RANDOMIZED BLOCK SPLIT PLOT EXPERIMENT ON NITROGEN COMPOSITION OF ALFALFA FORAGE

Source of Variation	Degrees Freedom	Sum of Squares	Mean Square	F. Term
Total	167	15.0917		
Reps.	2	0.1597	.0790	3.450*
Soils	3	0.1953	.0651	2.843*
Soil A vs. Soil B		.0119	.0119	.520
Topsoil vs. Subsoil		.0416	.0416	1.817
Main Plot Error	6	.1371	.0229	
Treatments:	13	10.1247	.7788	101.804**
Check vs. $CaCO_3$		.2234	.2234	29.203**
$CaCO_3$ vs. None		.2988	.2988	39.059**
R.P. vs. S.P.		.0569	.0569	7.438**[1]
S. Source vs. None		.0008	.0008	.105
$CaSO_4$ vs. S.		.0002	.0002	.026
N. vs. None		.0217	.0217	2.837
$CaSO_4$ vs. None		.0003	.0003	.039
$CaCO_3$ x R.P.		.2004	.2004	26.196**[2]
$CaCO_3$ x S.P.		.0417	.0417	5.451*
$CaCO_3$ + S.P. vs. S.P. Alone		.5822	.5822	77.105**
$CaCO_3$ + R.P. vs. R.P. Alone		.0258	.0258	3.373[1]
Treatments x Soils	39	3.6813	.0943	12.327**
Experimental Error	104	0.7954	.00765	

*Denotes significance at a 5% probability level.
**Denotes significance at a 1% probability level.
[1]Indicates that the second factor in the comparison is greater than the first.
[2]Indicates depressive interaction.

TABLE XVII

A MULTIPLE RANGE TEST SHOWING THE SIGNIFICANT DIFFERENCES OF NITROGEN UPTAKE DUE TO THE EFFECT OF TREATMENT

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .0253$

B. Shortest Significant Ranges: ($N_2 = 100$)

Range:	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(12)	(14)
(5% p-level) p =	2.80	2.95	3.05	3.12	3.18	3.22	3.26	3.29	3.32	3.36	3.40
R_p =	.0708	.0746	.0772	.0789	.0805	.0815	.0825	.0832	.0840	.0850	.0860

C. Results

Treatments:	1	2	12	4	5	7	13	9	10	6	8	3	11	14
Means Ranked In Order	0.291	0.484	0.965	0.993	1.008	1.017	1.031	1.053	1.053	1.054	1.054	1.058	1.078	1.277

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Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different. A broken line underscore indicates a similarity of treatments at a 5% p-level.

up, but the superphosphate was superior to the rock phosphate at the 1 percent probability level, Table XVI. Apparently the calcium carbonate treatment was the main factor here as the superphosphate treatments were a little lower than comparable treatments of rock phosphate until the calcium carbonate was added to the superphosphate, then this treatment was significantly higher than all other treatments at the 5 percent probability level, Table XVII. There was a depressive interaction between rock phosphate and calcium carbonate at the 1 percent probability level, and positive interaction between superphosphate and calcium carbonate at the 5 percent probability level, Table XVI. A highly significant F-term was obtained when comparing superphosphate plus calcium carbonate vs. superphosphate alone. Part, but not all, of the added nitrogen uptake could be attributed to an increase in yields. A slight decrease, although not enough for significance, in nitrogen uptake was noted in the rock phosphate plus calcium carbonate vs. rock phosphate alone pots. Neither of the sulfur sources had any significant effect in increasing the amount of nitrogen taken up.

The chief effect shown on nitrogen composition was due to calcium carbonate and not phosphorus, either superphosphate or rock phosphate. The difference here might be partly due to increased yields, but increased yields were brought about because conditions were made more favorable for nitrogen fixation. Increased yields might be interpreted to mean that with lime and phosphorus more nitrogen was made available than with phosphorus alone. Even though there was as much calcium available with rock phosphate as with superphosphate, the nitrogen content was greater with superphosphate. This possibly indicates that the amount of phosphorus in the plant as shown in Table VI may have a considerable bearing on the nitrogen content of the plant. There was a significant difference between replications at the 5 percent probability level. This may have been the effect of location of the pots on the greenhouse benches, as one and one-half replications were on one bench, and one and one-half replications on the other bench. It is concluded that the organic constituents of plants are sensitive to many more factors than just metallic elements. Difference may be due to light intensity, light quality, temperature, and humidity.

SUMMARY AND CONCLUSIONS

This thesis reports the results of a greenhouse experiment undertaken at the Oklahoma Agricultural and Mechanical College in 1954 and 1955, with the objective of seeking information that would increase knowledge on the use of phosphates and other fertilizers under Oklahoma conditions. The two soils that were used are quite extensive in Oklahoma and bear similar profile characteristics. These soils were separated into topsoil and subsoil samples, analyzed in the laboratory and then placed in greenhouse pots, which were arranged in a randomized block split plot design. Each soil was subject to thirteen fertilizers plus a check treatment.

Alfalfa plantings were made in each pot in September, 1954, and plants were grown under controlled conditions. The plants were harvested, as reported on page 15, and analyzed in the laboratory. The following conclusions are an evaluation of soils and their reaction to fertilizer treatments based on alfalfa yield and alfalfa composition data.

On yields after eight cuttings there was no significant difference between Soil A and Soil B and no significant difference between topsoil and subsoil. From this experiment, the soils from these two locations acted the same and from the same phosphate practice the soils should respond equally; or in other words, these two soils were probably the same soil insofar as the results this experiment show.

The percent phosphorus composition of plant material from Soil B was found to be significantly greater than that from Soil A. The topsoils were significantly more effective in increasing phosphorus composition of the plant than the subsoils.

A comparison of calcium uptake shows that Soil B was significantly more effective in increasing calcium uptake than Soil A. This was in reverse order of the effect of these soils in increasing potassium uptake which found Soil A to be significantly more effective than Soil B.

The effects of treatments in producing significant differences between plant yields, total nitrogen content, total phosphorus content, total potassium content, and total calcium content were evident in several instances. The amount of plant yield was noticeably increased in pots having rock phosphate and superphosphate additions when they were compared to the yield of the checks. Under the assumption that fifty percent of the phosphorus in rock phosphate was available to alfalfa, which was the original premise of the experiment, rock phosphate affected yields equally as well as superphosphate (at least under the conditions imposed by this experiment). Although the yield between rock and superphosphate was not significantly different, the superphosphate showed a significant increase over rock phosphate in phosphorus uptake by the plant.

There was a depressive interaction between rock phosphate and calcium carbonate. There was no significant change in yields by adding calcium carbonate to the rock phosphate treatment. There was a beneficial interaction between superphosphate and calcium carbonate, with this treatment being significantly higher in yields than all other treatments. The calcium carbonate treatment significantly increased the amount of calcium taken up from the superphosphate treatment. The calcium carbonate treatment lowered the amount of calcium taken up on the rock phosphate pots.

Potassium in these two soils was supposedly high enough for crop yields, but the availability of potassium and the amount of potassium taken up changed appreciably by the treatments added to the soil. Phosphorus increased the amount of potassium taken up, with little difference as to the two sources of phosphorus tested here. The amount of potassium was also raised appreciably by the addition of calcium carbonate.

Phibbs (45) found that for the first cutting of alfalfa, yields were raised significantly by the addition of nitrogen. After eight cuttings of alfalfa the yields were still higher from nitrogen treatment, but not enough for significance. Nitrogen taken up by the plant was significantly increased by the addition of phosphorus, with superphosphate being more efficient than rock phosphate; especially where lime was added in conjunction with the superphosphate. Calcium carbonate increased the uptake of nitrogen over the pots containing no calcium carbonate. Nitrogen taken up by the plant was not significantly increased by nitrogen fertilization. The chief effect shown on nitrogen composition of the alfalfa was due to lime and not phosphorus treatment, either superphosphate or rock phosphate. The increased nitrogen uptake might be due to increased yields, but the increased yields were brought about because conditions were made more available to plant growth. The agronomic constituents of plants are sensitive to many more things than just metallic elements. There was a difference possibly due to light intensity, light quality, temperature, and humidity.

The two sulfur sources added did not significantly increase the yield of the plants, nor did it increase the content of phosphorus, potassium, calcium, or nitrogen in the plant. It is concluded from the data that sulfur was not a limiting factor for these two soils tested.

LITERATURE CITED

1. Albrecht, W. A., and N. C. Smith. Calcium in relation to phosphorus utilization by some legumes and non-legumes. Soil Sci. Soc. Amer. Proc. 4:260-265. 1939.

2. Alway, F. J. A nutrient element slighted in agricultural research. Jour. Amer. Soc. Agron. 32:913-921. 1940.

3. Aslander, A. An attempt to solve the phosphate problem in crop production so as to economize with the worlds supply of phosphate. Review. Soil Sci. 79:487. 1955.

4. Bachtell, M. A. and V. W. Garth. Rock phosphate results inferior to those of superphosphate. Ohio Agr. Exp. Sta. Farm and Home Res. Bull. 271:59-60. 1951.

5. Bauer, F. C. The relationship of organic matter and the feeding power of plants to the utilization of rock phosphate. Soil Sci. 12:21-41. 1921.

6. Bear, F. E. and A. Wallace. Alfalfa, its mineral requirements and chemical composition. N. J. Agr. Exp. Sta. Bull. 748. 1950.

7. Beater, B. E. The value of preliming, primarily as a means of improving the adsorption of phosphorus by plants. Soil Sci. 60: 337-352. 1945.

8. Blaser, R. E., G. M. Volk, and F. B. Smith. The yield, composition, and nodulation of several clover varieties as affected by sources of calcium and phosphorus in combination with other fertilizers on several soils. Soil Sci. Soc. Amer. Proc. 6: 298-302. 1941.

9. Bledsoe, R. W., and R. E. Blaser. The influence of sulfur on yield and composition of clovers fertilized with different sources of phosphorus. Jour. Amer. Soc. Agron. 39:146-152. 1947.

10. Bradfield, R., G. Scarseth, and J. G. Steel. Factors affecting the retention of phosphorus by clays. 3rd Intern. Cong. Soil. Sci. 1:74-75. 1935.

11. Chaffin, W. A soil improvement program for Oklahoma. Okla. Ext. Cir. No. 412. 1945.

12. Cole, C. U., S. R. Olsen, and C. O. Scott. The nature of phosphate sorption by calcium carbonate. Soil Sci. Soc. Amer. Proc. 17: 352-356. 1953.

13. Cook, R. L. Divergent influence of degree of base saturation of soils on the availability of native, soluble, and rock phosphates. Jour. Amer. Soc. Agron. 27:297-311. 1935.

14. Copeland, O. L., and F. G. Merkle. The influence of certain soil treatments upon the fixation and availability of applied phosphates. Soil Sci. Soc. Amer. Proc. 6:321-327. 1941.

15. Crocker, W. Sulfur deficiency in soils. Soil Sci. 60:149-155 1945.

16. Dennis, E. J., and L. Chesnin. The availability of phosphorus to alfalfa in the horizons of four Eastern Nebraska soils. Soil Sci. Soc. Amer.Proc. 17:49-52. 1953.

17. DeTurk, E. E. The problem of phosphate fertilizers. U. of Ill. Agr. Exp. Sta. Bull. 484. 1942.

18. Dun, L. E. Effect of lime on availability of nutrients in certain Western Washington soils. Soil Sci. 56:297-316. 1943.

19. Duncan, D. B. Multiple range and multiple F test. Biometrics II, No. 1: 1-42. March 1955.

20. Fraps, G. S. Availability of the phosphoric acid of finely-divided rock phosphate. Tex. Agr. Exp. Sta. Bull. 509. 1935.

21. Fried, M. The feeding power of plants for phosphates. Soil Sci. Soc. Amer. Proc. 17:357-359. 1953.

22. Garman, W. L. Organic phosphates in Oklahoma soils. Okla. Acad. Sci. Proc. 28:89-99. 1947.

23. Graham, E. R. Availability of natural phosphates according to energy changes. Soil Sci. Soc. Amer. Proc. 19:26-29. 1955.

24. Hallock, D. L., and O. J. Attoe. Correlation of phosphorus content of alfalfa with pH and forms of soil phosphorus. Soil Sci. Soc. Amer. Proc. 18:64-67. 1954.

25. Harper, H. J. Easily soluble phosphorus in Oklahoma soils. Okla. Agr. Exp. Sta. Bull. 205. 1932.

26. ____________. Commercial fertilizer for Oklahoma crops. Okla. Agr. Exp. Sta. Bull. B-279. 1944.

27. Hutcheson, T. B., and M. H. McVickar. The use of nitrogenous fertilizers in the production of Virginia field crops. Va. Agr. Exp. Sta. Bull. 397. 1946.

28. Jones, U. S. Availability of phosphorus in rock phosphate as influenced by potassium and nitrogen salts, lime and organic matter. Jour. Amer. Soc. Agron. 40:765-770. 1948.

29. Marshall, C. E. The electrochemistry of the clay minerals in relation to pedology. 4th Int. Cong. Soil Sci. 1:71. 1950.

30. Metzger, W. H. Phosphorus fixation in relation to the iron and aluminum of the soil. Jour. Amer. Soc. Agron. 33:1093-1099. 1941.

31. McIntire, W. H. A new explanation of what happens to superphosphate in limed soils. Tenn. Agr. Exp. Sta. Bull. 176. 1941.

32. McLean, E. O. and J. E. Hoelscher. Factors affecting yields and uptake of phosphorus by different crops 1. Previous applications to the soil of rock phosphate and superphosphate. Soil Sci. 78:453-462. 1954.

33. ____________, D. A. Brown, and C. A. Hawkins. Comparative evaluation studies on rock and superphosphate. Ark. Agr. Exp. Sta. Bull. 528. 1952.

34. Moser, F. Fixation and recovery of phosphate from some lateritic soils. Soil Sci. Soc. Amer. Proc. 6:328-334. 1941.

35. Moss, A. D. The effect of several phosphate fertilizers on phosphorus penetration and soil fertility in a crop rotation on a Norge fine sandy loam. Masters Thesis Dept. of Agron. Okla. Agr. and Mech. College. 1954.

36. Murdock, J. T., and W. A. Seay. The availability to greenhouse crops of rock phosphate phosphorus and calcium in superphosphate-rock-phosphate mixtures. Soil Sci. Soc. Amer. Proc. 19:199-203. 1955.

37. Murphy, H. F. The role of kaolinite in phosphate fixation. Hilgardia 12:343-382. 1940.

38. ____________. Fertilizing wheat for yield and quality. Okla. Agr. Exp. Sta. Bull. 285. 1945.

39. Neller, J. R. The influence of sulfur and gypsum upon the composition and yield of legumes. Wash. Agr. Exp. Sta. Bull. 190. 1925.

40. ____________, G. B. Killinger, D. W. Jones, R. W. Bledsoe, and H. W. Lundy. Sulfur requirement of soil for clover grass pastures in relation to fertilizer phosphates. Fla. Agr. Exp. Sta. Bull. 475. 1951.

41. ____________, Effect of lime on the availability of labeled phosphorus of phosphates in Rutlege fine sand and Marlboro and Carnegie fine sandy loams. Soil Sci. 75:103-108. 1953.

42. Noll, C. F., and C. J. Irvin. Field test of phosphate fertilizers. Pa. Agr. Exp. Sta. Bull. 423. 1942.

43. Olsen, R. A., M. B. Rhodes, and A. F. Drieir. Available phosphorus status of Nebraska soils in relation to series classification, time of sampling and method of measurement. Amer. Soc. Agron. Jour. 46:175-180. 1954.

44. Pearson, R. W., R. Spry, and W. H. Pierre. The vertical distribution of total and acid soluble phosphorus in twelve Iowa soil profiles. Jour. Amer. Soc. Agron. 32:683-696. 1940.

45. Phibbs, G. M. The influence of phosphorus, lime, and fertilizers on alfalfa yields and composition. Master Thesis Dept. of Agron., Okla. Agr. and Mech. College. 1955.

46. Pohlman, G. G. Effect of liming deficient soil layers on yield of alfalfa and on root development and nodulation. Soil Sci. 62: 255-266. 1946.

47. Romine, D. S., and W. H. Metzger. Phosphorus fixation by horizons of various soil types in relation to dilute acid extractable iron and aluminum. Jour. Amer. Soc. Agron. 32:99-108. 1939.

48. Russell, D. A. A laboratory manual for soil fertility students. Wm. C. Brown Co. Dubuque, Iowa.

49. Russell, E. J. Soil conditions and plant growth. Longmans, Green, and Co., 8th Edition, London. pp 36-38. 1950.

50. Salter, R. M., and E. E. Barnes. The effeciency of soil and fertilizer phosphorus as affected by soil reactions. Ohio Agr. Exp. Sta. Bull. 553. 1935.

51. Scarseth, G. D. The mechanisms of phosphate retention by natural aluminosilicate colloids. Jour Amer. Soc. Agron. 27:596-616. 1935.

52. Smith, R. S. The differential response of two soil associations to rock phosphate. Agron. Jour. 42:495-497. 1950.

53. Snedecor, G. W. Statistical methods. The Iowa State College Press Ames, Iowa. 1946.

54. Stelly, M., and W. H. Pierre. Forms of inorganic phosphorus in the "C" horizons of some Iowa soils. Soil Sci. Soc. Amer. Proc. 7:139-149. 1942.

55. Swenson. R., C. V. Cole, and D. H. Sieling. Fixation of phosphates by iron and aluminum and replacement by organic and inorganic ions. Soil Sci. 67:3-32. 1949.

56. Vandecaveye, S. C. Effect of soil type and fertilizer treatment on the chemical composition of certain forage and small grain crops. Soil Sci. Soc. Amer. Proc. 5:107-119. 1940.

57. Volk, G. V. Availability of rock and other phosphate fertilizers as influenced by lime and forms of nitrogen fertilizer. Amer. Soc. Agron. Jour. 36:46-56. 1944.

58. Volk, N. J., J. W. Tidmore, and D. T. Meadows. Supplements to high analysis fertilizers with special reference to sulfur, calcium, magnesium, and limestone. Soil Sci. 60:527-535. 1945.

59. Weeks, M. E., and H. F. Miller. The residual effects of phosphates used on long time field experiments. Soil Sci. Soc. Amer. Proc. 13:102-107. 1948.

60. Yeats, P. A. Charts and maps showing fertilizer consumption in Oklahoma 1953-1954. Okla. State Bd. of Agr. 1954.

A P P E N D I X

PROFILE DESCRIPTION OF BETHANY SILT LOAM (SOIL A)

The sample referred to in this thesis as Type A was collected about 400 feet south and 200 feet west of the northeast corner of the southeast one-quarter, Section 33, Township 29 North, Range 2 East. The sample site was 4 miles north and 2 miles east of Newkirk in Kay County, Oklahoma. The site occupies gently sloping upland with convex slopes and has a gradient at the sample site of about one and one-half percent. At the time of sampling the area was in winter oats.

The soil profile is described as follows:

A_{1p} 0-8" Dark grayish brown (10 Yr 4/1.5; 2.5/2 when moist) silt loam weak medium granular; common fine pores; friable; permeable; pH 5.8 contains numerous fine roots, root hairs and partly decayed organic fragments; grades to the layer below.

A_3 8-15" Dark grayish brown (10 Yr 4/1.5; 2.5/2 when moist) light clay loam; moderate medium granular; friable to firm; permeable; pH 5.8 contains many fine pores, root hairs and root channels; in lower part there is a one inch transition of heavy clay loam in which there are very faint brownish gray films on the aggregates; grades shortly to the layer below.

B_{2-1} 15-26" Grayish brown (10 Yr 4/2; 2/2 when moist) clay; moderate medium to fine blocky; very firm; slowly permeable; sides of peds have weak shine; occasional strong brown specks; pH 6.0; sides of peds are subrounded in part; root hairs penetrate largely in spaces between peds; grades slowly to the layer below.

B_{2-2} 26-36" Grayish brown (10 Yr 5/2; 4/2 when moist) light clay with occasional yellowish brown mottles or streaks; weak medium blocky; very slowly permeable; pH 7.0 has definite tendency to shear in horizontal plane into nearly flat to wavy sheets 1/32 inch or less in thickness; contains more very fine sand than the layer above; occasional coarse quartz sand or very fine gravel particles; lower 4 inches contains occasional fine concretion of $CaCO_3$; grades to the layer below.

B_3 36–47"	Brown (10 Yr 5/3; 3/2.5 when moist) light clay much like the layer above but contains more fine concretions of $CaCO_3$; pH 7.5; less noticeable tendency to break out on horizontal planes; fine roots penetrate largely in spaces between aggregates; grades to the layer below.
C 47–60+	Grayish brown (2.5 Y 5/3) light clay streaked and mottled with pale yellow (5 Y 7/3) and light olive gray (5 Y 6/2); weak to moderate medium blocky; very firm; slowly permeable; pH 8.0; occasional fine and medium concretions of $CaCO_3$ and coarse dark yellowish brown splotches.

To the greatest depth sampled, the origin of material was not apparent. It could be either, old alluvium or residuum from moderately sandy shales. Occasional rounded chert fragments up to 4 inches in diameter are scattered on the soil surface.

PROFILE DESCRIPTION OF BETHANY SILT LOAM (SOIL B)

The sample referred to in this thesis as Type B was collected about 30 feet north and 30 feet east of the southwest corner Plot 5,100 of the Agronomy Farm, Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma.

The site occupies nearly level upland on which the slope is weak convex and the surface gradient is about 1 1/2 percent. The plot was in grain sorghum at the time of sampling.

The profile is described as follows:

A_{1p} 0-7" Grayish brown (10 Yr 4.5/2; 3.5/2 when moist) silt loam; weak medium granular; friable; permeable; pH 5.8; a few fine pores are present; rests with shear contact on the layer below.

A_1 7-12" Dark grayish brown (10 Yr 4/2; 3/2 when moist) silt loam; moderate medium granular, friable, many pores and fine root holes; pH 5.8; grades through a short transition to the layer below.

B_1 12-15" Dark grayish brown (10 Yr 4/2; 3/2 when moist) heavy silty clay loam, moderate medium subangular blocky; firm; slowly permeable; pH 5.8; sides of peds have a weak shine; grades to the layer below.

B_{2-1} 15-28" Dark grayish brown (9 Yr 4/2; 3/2 when moist) clay; moderate fine blocky; very firm; sticky and plastic when wet; very slowly permeable; pH 7.0; sides of peds are varnished and have strong clay films; occasional fine black concretions; grades through a 4 inch transition to the layer below.

B_{2-2} 28-36" Dark grayish brown (10 Yr 4/2; 3/2 when moist) clay; weak angular blocky; very firm and compact; very slowly permeable; pH 7.5; occasional fine black pellets; a few strong brown specks about the tiny root holes; many fine $CaCO_3$ concretions below 24 or 26 inches; peds have a weak shine when moist; grades through a 3 inch transition to the layer below.

B_3 36-44" Brown (7.5 Yr 5/4; 4/3 when moist) light clay; weak medium blocky; firm or very firm; occasional black pellets and $CaCO_3$ concretions; pH 7.5; sides of peds have weak coatings of dark brown (7.5 Yr 4/2 when moist); grades to layer below.

C_1 44-52" Reddish brown (5 Yr 5/4; 4/4 when moist) heavy silty clay loam or light silty clay much like the layer above; occasional large $CaCO_3$ concretions and black ferruginous films; pH 7.5+; grades to layer below.

C_2 52-64" Reddish brown (3.5 Yr 5/4; 4/4 when moist) silty clay loam splotched with ten percent of red (2.5 Yr 4/6) has occasional light gray streaks; weak irregular blocky; firm; slowly permeable; pH 7.5; occasional fine black pellets and fine concretions of $CaCO_3$; grades to layer below.

C_3 64-84"+ Red (2.5 Yr 4/6; 3/6 when moist) silty clay with occasional light gray streaks and splotches; weak medium blocky; firm but not compact; pH 7.5+; many fine pores; changes little to greatest depth sampled. It is likely that this substratum is in old alluvium.

TABLE XVIII

ANALYSIS OF VARIANCE OF THE SPLIT PLOT DESIGN SHOWING THE COMPARISONS MADE

Source of Variance	Comparisons	Degrees of Freedom
TOTAL		167
Replications		2
Soils:		3
Soil A vs. Soil B		1
Topsoil vs. Subsoil		1
Reps. x Soils (Error A)		6
Treatments:		13
Check vs. $CaCO_3$	1 vs. 2.	1
$CaCO_3$ vs. No $CaCO_3$	2,4,6,8,11,14, vs. 1,3,5, 7,10,12.	1
R.P. vs. S.P.	3,4,9, vs. 12,13,14.	1
S. Source vs. None	7,8,10 vs. 3,4,9.	1
$CaSO_4$ vs. S.	5,6 vs. 7,8.	1
N. vs. None	9,10,11,13 vs. 3,7,8,12.	1
$CaSO_4$ vs. None	5,6 vs. 3,4.	1
$CaCO_3$ x R.P.	4,1 vs. 2,3.	1
$CaCO_3$ x S.P.	14,1 vs. 12,2.	1
$CaCO_3$ + S.P. vs. S.P. Alone	14 vs. 12.	1
$CaCO_3$ + R.P. vs. R.P. Alone	4 vs. 3.	1
Treatments vs. Soils		39
Experimental Error		104

VITA

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Master of Science

Thesis: THE EFFECT OF VARIOUS FERTILITY TREATMENTS, INCLUDING PHOSPHORUS, CALCIUM, NITROGEN, AND SULFUR ON THE YIELD AND COMPOSITION OF ALFALFA GROWN ON BETHANY SILT LOAM.

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