THE INFLUENCE OF PHOSPHORUS, LIME AND FERTILIZERS ON ALFALFA YIELDS AND COMPOSITION

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INTRODUCTION

It is questionable whether any element in the soil might be considered the most important, yet, Pierre (39)[1] attributes low crop production to be due to the lack of phosphorus more than any other element.

Plant yields on many Oklahoma soils are limited by the ability of the soil to furnish necessary amounts of phosphorus for maximum plant growth. Exploitative farming systems, erosion, and leaching have caused many Oklahoma soils to become depleted of their native fertility in a relatively short period of time (10,22). Crop yields can be restored to a satisfactory level on many of these soils by the use of phosphorus fertilizers.

Differences have been found in the capacity of several phosphate fertilizers to increase crop yields. Such difference are often related to soil and plant characteristics, for instance, some workers (16,39,44) agree that many plants will give a better response to rock phosphate on acid soils than on neutral to basic soils. Other results[2] have shown that plant specificity is a determining factor instead of particle size in the response of legumes to rock phosphate fertilization.

Many workers (7,16,23) contend that the ultimate goal of adding fertilizing materials to the soil is to establish a nutrient balance. Consequently, an objective point is to seek a combination of factors under Oklahoma conditions that will lead to the most efficient use of

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[1]Numbers in parenthesis refer to literature cited in bibliography.
[2]Unpublished data. W. L. Garman and H. J. Harper, Agronomy Department, Oklahoma Agricultural and Mechanical College, 1950.

phosphate.

Recent investigations made (32) at this station show, that after a period of time, rock phosphate will penetrate to some extent into the profile of a medium textured soil. The variation of phosphorus distribution in several soil profiles was reported by Pearson (38). Dennis (15) showed that soil phosphorus in the C-horizon was very effective in supporting plant growth and that the nitrogen and phosphorus content was higher than in plants grown on other horizons. Such studies may suggest in part the relative importance of available phosphate supply in the immediate root zone.

The proposed objectives of this experiment were as follows: (1) To study the effects of sulfur, nitrogen, and calcium carbonate on the utilization of rock phosphate as compared to superphosphate. (2) To observe the influence of top soil and subsoil placement on the effectiveness of these fertilizers.

REVIEW OF LITERATURE

The need for replenishing the phosphorus supply in Oklahoma soils was discussed by Chaffin (10) who called attention to the factors contributing to the depletion of soil fertility. Other investigators (24) also note a rapid decline in fertility of cultivated soils from their virgin state. Many soils in central and eastern Oklahoma have been severely leached of their calcium, leading to an acid soil reaction. The presence of acidity and the degree of acidity is closely related to the annual rainfall which increases from west to east. As the acidity of these soils increase, not only the availability of phosphorus and other essential elements is lowered but the total amount is lowered as well.

Harper (23) evaluated the use of commercial fertilizers on the prairie soils of central and eastern Oklahoma. He considered these soils as a unit and with the support of crop yield and chemical composition data, he contended that phosphorus was a limiting factor in crop yield. Plant yields were also increased in most cases from nitrogen applications as well as from potash amendments. Murphy (33) reported favorable wheat yields from a phosphorus-nitrogen combination.

Organic matter functions, in part, as a reservoir of nutrient elements and from the standpoint of economy, many investigators (10,23) recommend the return of plant material to the soil as a means of replenishing depleted nutrients. This is especially true when proteinaceous plant material is plowed under as a green manure crop to increase the potential nitrogen supply of a soil. Organic matter cannot be disregarded as a phosphorus donor. Garman (22) presented data, obtained from a study of the profiles of some thirty Oklahoma soil types, which showed that organic phosphates were utilized by plants at a rate equal to inorganic phosphates.

Various workers (28,31,45) have found that most phosphate compounds added to the soil for the purpose of correcting phosphate deficiency have, in a period of time, become unavailable to the plant. The consensus of opinion has been that soils of high and low pH contain materials that form insoluble complexes with phosphorus and render it unavailable. In a review of soil phosphorus, Dean (12) used the term "availability" as an index of a soil's phosphorus supplying power, and outlines the graduated degrees of unavailability by which phosphorus is linked with the solid soil phase. The complex fixation-mechanisms and soils in which they function bear integrated relationships as evidenced by the many forms of soil phosphates. The prevalence or activity of a fixing mechanism in a soil depends upon many soil factors. Thornton (50) by use of the Neubauer method of testing the availability of phosphorus from phosphate fertilizing materials, pointed to the relative influence of soil pH, soil types, and combinations with other fertilizing materials as the chief criteria for phosphorus availability.

Olson (37) reported on a study of soluble phosphorus extracting agents for a range of soils. He stated that soluble phosphorus, pH, and plant yield response were closely related to soil series. Therefore, he contended that good soil series classification was a valuable indication of probable phosphorus fertility status of the soil. The amount of phosphorus and its chemical form not only varies from soil to soil but it varies within individual horizons (8,15,38). Allaway (2) cited the effect of the processes of soil genesis upon the chemistry of phosphorus in soils. He studied the profile distribution of phosphorus in a number of Nebraska soils and found that in highly developed profiles phosphorus was concentrated in the "A" horizon, probably due to plant action. The total phosphorus content of soils with lime zones was generally at its maximum at the top of the limed zone. Soils investigated that were formed under slightly acid to acid conditions contained increasing amounts of iron and aluminum phosphates as the depth of profile increased.

Definite conclusions regarding the distribution of total and acid-soluble phosphates in soil profiles were also reported by Pearson (38), who in agreement with Allaway (2) stated that differences in phosphorus forms and their concentration were related to soil forming processes. Results of his experiments showed that the amounts of total phosphorus decreased with depth from the surface layers to a minimum percentage at a zone ten to thirty inches in depth. Generally, below this zone there was a marked increase of total phosphorus up to a maximum in the "C" horizon. In a majority of the profiles studied the concentration of acid-soluble phosphorus followed a similar trend. The author did not find a close correlation between soil pH and the easily -soluble phosphorus content of respective horizons, but did note that from twenty-five to fifty-four percent of the total phosphorus in the lower horizons was acid-soluble. These acid-soluble phosphates of the lower horizons were assumed to be iron and aluminum phosphate compounds, but evidence for this assumption was not furnished.

By using a system of phosphate mineral solubility curves, Stelly et al. (49) undertook the identification of phosphorus forms in the "C" horizon of some Iowa soils. Apatites, tri-calcium phosphates and ferric phosphates were representative of acid-soluble phosphates, while aluminum and ferrous phosphates were more soluble with basic extractants. The forms of extractable phosphorus were found to vary greatly between soil types and were generally not representative of any one phosphate mineral, but were present as combinations. Of particular interest was the reaction of plants when grown on media containing identified phosphate minerals. A generalization of the outcome of these studies showed that ferric phosphate was a poor source of phosphorus for either alfalfa or corn, and apatite forms of phosphorus largely benefited alfalfa, while aluminum and ferrous phosphates were relatively available to both plants.

Dennis (15) found a sizeable variation in the amount and distribution of total phosphorus in profiles of Nebraska soils. Soluble phosphorus extracted by solutions buffered to pH of three and nine gave results which suggested that calcium or iron and aluminum phosphates were present and the solubility rates of these forms were not the same in all soils. To measure the relationship of phosphorus availability within the horizons of the four soils studied, Dennis used elemental composition percentages and yields of alfalfa as criteria for evaluation. A supplemental phosphorus application of one-thousand pounds of soluble P_2O_5 per acre increased the yields and the total nitrogen content of the alfalfa plants in all cases over the check treatments. There was a highly significant interaction between treatment and horizon as determined by measuring alfalfa yield indicating, in part, different availability levels of phosphorus between horizons. Chemical analyses showed the "C" horizon of an acid loess soil to contain the highest amount of soluble phosphorus. This soil consequently produced the highest plant yields and furnished more nitrogen and phosphorus for plant growth than any other untreated soil. Supplemental phosphorus additions were credited with lowering the cation content of alfalfa top growth, thereby, reducing calcium percentages.

The quick test of the surface soil for available phosphorus and surface reaction did not give satisfactory explanations for differences in response of soils to rock phosphate applications according to Smith (47), who obtained many different correlations. He suggests that soil associations regardless of location will respond to rock phosphate in a similar manner.

The application of lime to a soil to which rock phosphate has been applied retards the processes by which rock phosphate is converted into a more available form. This fact was noted by Salter and Barnes (44) who found that the relative efficiency of rock phosphate at pH 7.5 was only ten percent that of superphosphate. McGeorge (28) reported that additions of sulfuric acid to irrigation water greatly increased the absorption of phosphorus by plants from alkaline calcareous soils. The majority of literature citations supports the idea that a great many variables influence phosphorus-lime associations, but on a heavily limed soil it was generally agreed that the phosphate applications that gave the more desirable effect to plant yields were the more acidic forms (16,20,51). Plants in the field are considered by Russell (43) to be relatively inefficient users of phosphates, for rarely more than twenty to thirty percent of the amount supplied as fertilizers is taken up. McIntire (29) furnished a partial explanation of low availability of phosphorus when he stated that fluorides in commercial fertilizers are capable of generating calcium fluorophosphates. These compounds, he states, are analogous to fluorapatite of some rock phosphates and are highly unavailable to plants.

In acid soils lime is generally credited with the ability to make more of the phosphorus of an added phosphate available to crops. With this assumption in mind, Neller (34) conducted tracer studies with labeled phosphates applied with lime on sandy Florida soils. Results from pot tests showed that additions of enough lime to raise the soil pH from 5.6 to 6.7 had no significant effect on the percentage of labeled phosphorus taken up by oats from superphosphate. Results of field tests were appreciably the same; lime did not affect the uptake of phosphorus from low to high lime levels.

Albrecht (1) called attention to the close calcium-phosphorus linkage and cited that plant behavior shows the two are used in combination. In an effort to study the functions of calcium as an exchange ion, he undertook to determine the uptake of phosphorus in connection with different amounts of calcium offered and concluded that calcium becomes a cation carrier for soil-plant exchanges of elemental phosphorus and nitrogen. Albrecht noted that at low levels of soil calcium elemental phosphorus and nitrogen were possibly moved from plant seedlings to the surrounding soil, because at low soil calcium levels seedlings contained less phosphorus and nitrogen than was in the original seed. However, phosphorus and nitrogen moved into the plant at high levels of calcium saturation. The author furnished two explanations for these phenomena; one, phosphorus and nitrogen, both constituents of protein, are possibly metabolized into insoluble protein; two, calcium may activate the plant root membrane. Both explanations would effect movement equilibrium in favor of plant uptake.

Pohlman (40) supported the theory that the degree of response to liming cannot be predicted from studies of the surface soil only, and he emphasizes the importance of the subsurface in determining the fertility status of soils. Such conclusions were made after he received three fold increases in alfalfa yields from lime applications at the sixteen to twenty-four inch subsurface soil layer.

Although soil reaction and the activity of calcium in a soil are often spoken of as inseparable, Wattenpaugh (53) called attention to the extreme importance of calcium to plant-root development. He found that the depth of root penetration was closely related to alfalfa yields, and that the activity of root nodulation and zone of root development was definitely correlated with the pH and the replaceable calcium of a soil. He received favorable root growth above pH 5 and a retarded root growth below pH 4.5. Anion exchange, a mechanism of phosphate retention in some soils, was investigated by Dean and Rubins (14) and evidence was furnished by these investigators that phosphorus as an exchangeable ion could be replaced by other anions, depending somewhat on the activity and concentration of each. Further investigation of the surface activity of soil phosphorus was made by Seatz (46). By introducing tagged phosphorus into soils, he measured the kinetic exchange between soil-held-phosphorus and infused radio active phosphorus and found an exchange reaction taking place in three distinct phases, an initial absorption phase up to one hour, a second phase from one to thirty-six hours and a prolonged interaction after thirty-six hours. He suggested that the three levels of dissociation might reflect the phosphorus supplying powers of a soil. Seatz also illustrated by desorption techniques the presence of an anion exchange mechanism. Sulfate, arsenate, and fluoride ions were credited to be very effective in displacing phosphate ions from a solid phase.

Crocker (11) reviewed the importance of sulfur in animal nutrition and pointed directly to the benefit of sufficient available amounts of this element in soils. Sulfur is essential to plants in the synthesis of proteins, thereby, from the standpoint of crop production, it bears close relationship with phosphorus and nitrogen in legumes. Russell (43) designates a large region in the central and western United States extending into Canada where yields of leguminous crops are limited by the amounts of a sulfate given in a fertilizer, and increases in plant yields ranging from fifty percent to ten-fold can be brought about by application of two hundred to four hundred pounds of gypsum per acre. Studies (3) in Montana show a difference in alfalfa yields and protein content due to the source of sulfur used.

The superiority of superphosphate as a phosphate carrier may have been partially solved by Bledsoe and Blasier (9) who applied elemental sulfur in conjunction with different phosphates on a sulfur deficient soil, and related plant yield differences to the presence of sulfur in the phosphorus soil amendments. Results from field plot tests showed that rock phosphate applied at the rate of 2,000 pounds per acre plus a 60 pound per acre sulfur treatment was equal to superphosphate in respect to clover yields. All phosphorus plus sulfur treatments increased clover yields when compared to the phosphate applied alone with the exception of superphosphate which showed little response to additional sulfur. Composition of clovers grown under the conditions of this experiment showed that the clovers fertilized with sulfur contained a significantly higher percentage of sulfur with all phosphorus sources with the exception of superphosphate. An increase in nitrogen content apparently was due to sulfur treatment, but the percentages of potassium, calcium, and magnesium were decreased.

Present day high analysis fertilizers should be supplemented with sulfur, calcium and other elements when applied to the soil according to Volk (52), who by means of a greenhouse study determined the relative efficiency of elemental sulfur and gypsum on a number of common crop plants. Applications of equivalent amounts of sulfur in the form of gypsum, elemental sulfur and superphosphate to each of five soils suspected of being low in sulfur increased both plant yield and the concentration of sulfur in the plant material. Increased uptake of sulfur from elemental sulfur over gypsum by the plant was shown after allowing the elemental sulfur sufficient time to oxidize in the soil before the crop was planted. One thousand pound per acre applications of lime in conjunction with sulfur increased plant yields, but decreased the percent SO_3 in the plant tissue. Mitchell (30) stated that a lapse of time or ageing period for elemental sulfur had a beneficial effect on the phosphorus solubility of di-calcium phosphate, a relatively insoluble compound. Neller (35) used gypsum to correct sulfur deficiencies in sandy Florida soils. The sulfur supplement not only increased yields, but improved the quality of forage due to a higher protein content. Significant increases in calcium uptake were noted and he claimed that the increased uptake of sulfur, nitrogen, and phosphorus was due to the effects of gypsum.

The results of workers in widely separated regions call attention to the soil conditioning properties of gypsum. Baghott (4) reclaimed some alkali problem soils of California with heavy applications of gypsum. Gypsum increased water penetration, lowered pH, and in general improved soil conditions for alfalfa growth and was more active in these respects than were equivalent amounts of sulfur. Rinehart (41) found that 2,000 pound per acre applications of gypsum improved drainage of wet spots on New Jersey soils by twenty percent. This was presumed to be due to flocculation of fine soil particles and a motivation for aggregation.

Nitrogen compounds added to soils in combination with phosphate materials have a direct influence on the solubility of the accompanying phosphorus. Fudge (21) acknowledged this fact, and states that the solubility of the phosphorus is directly influenced by the type of nitrogenous fertilizer used. Of major concern is the residual effects of the nitrogen supplement on soil reaction, the exchange complex, and the concentration and nature of ions left in the soil solution. Higher pH values in a soil are often brought through the use of sodium nitrate, calcium nitrate, and calcium cyanamide, whereas the use of urea and ammonium additives have an opposite effect on soil reaction. The extent that residual cations might influence phosphorus solubility depends upon the many soil conditions present. Fudge further states that if basic nitrogen fertilizers do increase phosphorus availability, then fertilizers that leave a sodium residue are more instrumental in the increase of availability than fertilizers leaving a calcium residue. Jones (25) found that a ninety-eight percent increase in uptake of phosphorus by rye plants was due to the acidifying action of ammonium sulfate on rock phosphate treatments when the two were applied together. The conclusions of Volk (51) were in agreement with the above author in relation to the superiority of physiologically-acid nitrogen fertilizers versus the so-called basic fertilizers when using relatively insoluble phosphates as phosphorus sources. Volk received a decreased uptake of calcium in oat and sorghum plants when ammonium sulfate was used as a nitrogen source, and a decided decrease in calcium uptake as the result of sodium nitrate fertilization.

The phosphorus content of oat forage produced on field plots was increased by the application of phosphorus without nitrogen in studies made by Domby (18). A top dressing of seventy-two pounds of nitrogen per acre reduced the phosphorus content of the oat forage, but due to increased yields more phosphorus was removed on an acre basis.

Lorenz (27) reported significant differences in uptake of phosphorus by plants in a greenhouse study on calcareous California soils when the composition of plants grown on ammonium sulfate soil treatment were compared with those grown on calcium and sodium nitrate treatments. The interrelation of nitrogen source and phosphorus availability, the author explained, was largely due to the ammonium ion altering the calcium ion activity and in turn increasing the solubility of the soil phosphates. Dion (17) working with calcareous soils found no statistically significant effect of nitrogen on phosphorus uptake, but did note a close correlation between phosphorus content and plant growth and, consequently, concluded that differences in phosphate carriers depend largely on calcium activity.

Beeson (7) refers to the net effect of nitrogen as a function of many soil characteristics. He reports that nitrogen might help to increase the ratio of protoplasm to cell wall material, and being a "vegetative-builder" is instrumental in decreasing the ratio of calcium to dry matter.

Several workers including Dean (13) have found that the phosphorus composition of plants is directly proportional to the availability of soil phosphorus. Dean showed by tracer techniques that the absorption of phosphorus fertilizer by plant is inversely proportional to the phosphorus fertility status of the soil. Nelson (36) corroborated these results when he reported higher uptake of soil phosphates when fertilizer phosphates were at low levels. Plants vary in the ability to absorb phosphates (13,26). Bear (6) recognizes alfalfa as an outstanding plant in terms of yield and feeding value, and calls attention to its high elemental requirements, which includes a high demand for available phosphorus.

Problems connected with phosphate usage are best solved by considering both plant requirements and soil factors according to DeTurk (16). He bases his investigations and recommendations on rock phosphate and superphosphate, the two most common forms. He generally associates rock phosphate with legumes, as feeders on phosphates of low solubility; and superphosphate with wheat and corn, which demand phosphates of higher solubility. He considers superphosphate to be a means of increasing productivity on an already fertile soil, and rock phosphate to be an economical material for building up the productive level of many phosphorus deficient soils. Consequently, he suggests these two forms of phosphate should be used as a team.

METHODS AND MATERIALS

The data included in this thesis are material gathered 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.

Description of the Soils Studied

The two soils used in this study were similar in profile characteristics and were tentatively 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. The area had been under continuous small grain production for at least fifteen 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 when lime was added.[2]

The soil sample referred to as "Soil B" was taken from a plot on the Oklahoma Agricultural and Mechanical College Agronomy Farm, west of Stillwater, Payne County, Oklahoma. This soil was from a plot under a four year rotational cropping system of cotton, small grains, darso, and clover. The rotation has been carried on since 1917 and each season all top growth had been removed. The soil samples were taken in May, 1954.

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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.

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 one was a sample of topsoil taken from the Bethany silt loam (Soil A), and soil number two represents the subsoil. In the same order, soil number three was a sample taken from the topsoil of the Bethany silt loam (Soil B) and soil number four corresponds to the subsoil. Each soil was mixed thoroughly and sieved through a quarter-inch mesh screen and allowed to air dry. After sufficient time was allowed for the soil to dry, 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 meter. Fifty grams of the soil were mixed with an equal weight of water and readings were taken after allowing sufficient time for equilibrium.

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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

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 (42). 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 ammonium ion was then displaced by addition of magnesium oxide and measured quantitatively.

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

The exchangeable calcium in milliequivalents per 100 grams of soil was found by precipitation of calcium as calcium oxalate from the ammonium acetate leachate. Quantitative measurements were made by standard permanganate titrations.

Total phosphorus and acid-soluble phosphorus were determined colorimetrically.

Greenhouse Procedure

The two-gallon glazed, non-porous jars, that were used in this study, were washed and rinsed with distilled water before the soil was placed in them. The drain holes in the jars were closed with rubber stoppers.

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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.

On September 28, 1954, plantings were made. Alfalfa seeds 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 split plot design, and remained in the same arrangement throughout the experiment. On November 1, 1954 the soil in each pot was inoculated with Rhizobium bacteria culture, 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 the mixture 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.

On January 28 and 29, 1955, the alfalfa plants were harvested in the early blossom stage (1/3 bloom). All plant material was clipped one and one-half inches above the soil surface and immediately autoclaved in order to stop all metabolic activity. After autoclaving, to facilitate ease of weighing and to bring the plant material to a constant weight, the alfalfa tops were placed in a forced-air drying oven and dried at sixty degrees centigrade for a forty-eight hour period. The plant material was weighed and yield weights listed in Table III.

Before further laboratory analyses were made, the dried plant material was ground to pass a twenty mesh screen and then analyzed for percent nitrogen and phosphorus.

All yield and composition data were analyzed statistically according to the split plot method of Snedecor (48), and multiple range tests of soils and treatments were made as recommended by Duncan (19). The comparisons of sources of variation in plant yields and composition were made as in Table XV.

Soil Treatments

Fertilizer treatments were applied to the soil two days before the date of seeding. Lime was thoroughly mixed with all of the soil in the pots, while all other materials were mixed into a top two inch layer of the 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 and was added to the soil in an amount calculated to bring the calcium saturation of the soil to eighty percent of the total exchange capacity. Consequently each soil required a different rate of calcium fertilization. This rate, once established, was used consistently throughout. All other calcium containing compounds were taken into consideration and adjustments were made as to the amount of calcium added.

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 where ever rock phosphate additions were made. It was calculated that thirty-three percent of rock phosphate added was P_2O_5 and assuming one-half of this to be available, then approximately one-hundred and sixty-five pounds of soluble

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 Pot #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 Pot #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 Pot #2)
9	Rock Phosphate Ammonium Nitrate	1,000 lbs. 86 lbs.
10	Rock Phosphate Ammonium Nitrate Sulfur	1,000 lbs. 86 lbs. 53 lbs.
11	Rock Phosphate Ammonium Nitrate Sulfur Calcium Carbonate	1,000 lbs. 86 lbs. 53 lbs. (Specific to soil as in Pot #2)
12	$Ca(H_2PO_4)_2$ Calcium Sulfate	293 lbs. 225 lbs.
13	$Ca(H_2PO_4)_2$ Calcium Sulfate Ammonium Nitrate	293 lbs. 225 lbs. 86 lbs.
14	$Ca(H_2PO_4)_2$ Calcium Sulfate Calcium Carbonate	293 lbs. 225 lbs. (Specific to soil as in Pot #2)

P_2O_5 per acre was added to each pot. This assumption was based on data reported in the literature (43,5).

The treatment referred to as superphosphate was calculated as follows: Chemically pure laboratory reagents, monobasic calcium phosphate and calcium sulfate, were added in amounts equivalent to the soluble P_2O_5 and gypsum that might be expected in an 825 pound per acre application of twenty percent superphosphate. The 825 pound per acre figure with twenty percent soluble P_2O_5 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 chemically pure ammonium nitrate from the laboratory shelf was used. Nitrogen requirement was calculated from the assumption that a three ton per acre crop of alfalfa with a 2.2 percent nitrogen composition would remove one-hundred and thirty-two pounds of nitrogen per year. With the assumption that the plants would take two-thirds of this nitrogen for the first crop or eighty-six pounds from the soil, further calculations showed that two-hundred and fifty-eight pounds per acre of ammonium nitrate, would be required.

The amount of calcium sulfate or "gypsum" supplement was based upon the two-hundred and twenty-five pound application included in the superphosphate treatment. Analytical reagent calcium sulfate provided the "gypsum" source for this treatment.

Application of elemental sulfur was made to correspond to the sulfur content of the gypsum treatment. On this basis fifty-three pounds of sulfur per acre should theoretically be equivalent to a two-hundred and twenty-five pound treatment of gypsum. A precipitated form of sulfur (flowers of sulfur) served as the source for this element.

Chemical Analyses of Plant Material

Before the chemical analyses were made, the dried plant tissue was ground to pass a twenty mesh screen and then analyzed for percent total nitrogen and total phosphorus content.

A colormetric procedure outlined by Harper[1] was used to determine the percent total phosphorus. One-half gram samples of plant forage were digested in five milliliter amounts of a solution containing three parts concentrated nitric acid and one part seventy to seventy-two percent perchloric acid. After digestion the samples were brought to a two-hundred milliliter volume with distilled water and forty milliliter aliquots were withdrawn to develop a color test. 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 absorption readings on the Fisher electrophotometer. The readings obtained were converted into milligrams of phosphorus by consulting a color density curve set up from a set of solutions containing known amounts of phosphorus.

The total nitrogen was determined by the Kjeldahl method. A one gram sample of plant forage was digested by sulfuric acid in the presence of selenium. Nitrogen in the form of ammonia was distilled over into a receiving flask containing fifty milliliters of 0.08091 N hydrochloric acid solution. After distillation the excess acid in the receiving flask was titrated with 0.0870 N sodium hydroxide using methyl red - methylene blue as an indicator and total nitrogen was calculated by means of a conversion factor.

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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.

RESULTS AND DISCUSSION

The Yield of Alfalfa Forage

Scientific methods of farming and modern techniques used in agriculture tend to place this industry on a mass production basis. A factor that is of major interest to the layman and one that is supported by visible evidence is a crops's yield per given area. It is quite generally agreed that a multitude of conditions influence the final yield, for instance, Smith (47) points to cropping systems as a cause for the difference in behavior of soils. Other workers (15,35) show that internal soil characteristics may provide information to the adaptability of crops. Neller (34) associated yield differences with soil type. Consequently, data taken from alfalfa yields in a greenhouse study such as the one reported here might logically be expected to vary considerably between soils.

The Effect of Soils on Yields

Daily observance of plant growth indicated that plant responses were influenced by the soil from which they obtained support. During the early stages of the experiment, the top growth of alfalfa on Soil 2 was larger than the growth from any other soil. It was noted that the alfalfa top growth on Soil 2 seemed to reach a leveling off period and then plant growth from the two topsoils surpassed it. No two soils produced equal alfalfa yields and the soils consequently, could be ranked from the standpoint of forage production. The soils ranked in this manner would place Soil 2 with 245.2 grams first, followed in descending order by Soil 4 with 238.2 grams, Soil 1 with 197.3 grams and Soil 3 with 184.6 grams of alfalfa top yield. Statistical analysis of alfalfa yields are given in

TABLE III

WEIGHTS IN GRAMS OF ALFALFA FORAGE YIELDS GROWN IN GREENHOUSE POTS

Treatments		Reps.	Soil #1	Soil #2	Soil #3	Soil #4
		1	3.070	1.372	1.425	*
1.	Check	2	3.020	1.482	2.008	
		3	3.825	1.362	1.615	
		1	4.225	2.195	3.810	*
2.	$CaCO_3$	2	4.090	2.236	2.750	
		3	5.480	2.750	3.240	
		1	3.265	4.910	4.230	6.327
3.	R. Phos.	2	4.880	6.695	4.460	6.630
		3	5.180	7.585	4.458	6.170
		1	3.870	7.680	4.648	4.000
4.	R. Phos.	2	6.135	6.415	4.390	6.128
	$CaCO_3$	3	6.805	6.885	4.858	6.330
		1	4.090	6.275	4.210	6.905
5.	R. Phos.	2	4.315	7.000	4.355	7.420
	$CaSO_4$	3	3.590	6.700	5.440	7.270
	R. Phos.	1	5.570	6.550	4.735	4.615
6.	$CaCO_3$	2	5.090	6.007	4.580	5.925
	$CaSO_4$	3	6.002	5.960	4.905	6.960
		1	4.690	7.243	3.993	6.055
7.	R. Phos.	2	3.943	7.620	4.085	7.070
	Sulfur	3	4.310	6.240	4.580	7.110
	R. Phos.	1	4.745	3.895	5.130	4.300
8.	Sulfur	2	4.468	6.670	5.125	5.080
	$CaCO_3$	3	5.905	6.790	5.123	6.595
		1	4.430	6.103	4.348	8.865
9.	R. Phos.	2	4.805	6.895	4.752	7.330
	Nitrogen	3	3.840	6.895	4.253	8.405
	R. Phos.	1	3.955	5.410	4.560	6.980
10.	Nitrogen	2	3.982	6.348	4.740	7.808
	Sulfur	3	4.470	6.595	4.815	7.055
	R. Phos	1	4.040	6.828	5.485	5.278
11.	Nitrogen	2	5.248	5.335	5.822	6.290
	Sulfur	3	6.420	7.178	5.905	7.310
	$CaCO_3$					
		1	3.640	5.615	4.285	5.710
12.	S. Phos.	2	4.345	6.375	4.940	5.675
		3	4.765	6.695	4.655	6.628
		1	5.395	7.230	4.500	7.185
13.	S. Phos.	2	4.775	6.390	4.715	6.885
	Nitrogen	3	5.523	6.555	4.630	7.700
		1	6.170	6.550	4.415	7.598
14.	S. Phos.	2	5.430	6.930	4.995	7.020
	$CaCO_3$	3	6.200	6.855	4.690	7.760

*Yields were unharvested due to insufficient plant growth.

TABLE IV

ANALYSIS OF VARIANCE OF SPLIT
PLOT EXPERIMENT ON ALFALFA YIELDS

Source of Variation	Degrees Freedom	Sum of Squares	Mean Squares	F. Term
Total	167	533.729		
Reps.	2	9.871	4.935	16.29**
Soils	3	63.429	21.143	69.80**
Soil A vs. Soil B		2.516	2.516	8.30*
Topsoil vs. Subsoil		60.740	60.740	200.53**
Main Plot Error	6	1.817	.302	
Treatments:	13	281.067	21.620	60.85**
Check vs. Others		163.639	163.639	460.56**
Check vs. $CaCO_3$		5.603	5.603	15.77**
Check vs. R.P. Alone		86.681	86.681	245.55**
Check vs. S.P. Alone		81.214	81.214	228.57**
$CaCO_3$ vs. No $CaCO_3$		5.015	5.015	14.11**
Phos. vs. No Phos.		202.979	202.979	571.29**
R.P. vs. No R.P.		143.448	143.448	403.73**
S.P. vs. No S.P.		161.135	161.135	453.51**
R.P. vs. S.P.		.430	.430	1.21
S. Source vs. None		.380	.380	1.07
S. vs. $CaSO_4$		.285	.285	.80
N. vs. No N.		4.760	4.760	13.39**
Lime-Phos. interaction		.957	.957	2.69
Treatment x Soils	39	344.496	8.833	24.86**
Experimental Error	104	36.955	.355	

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

Table IV. The results in this table show significant differences between the amounts of alfalfa forage yield produced from soils.

When the yields from Soil A were combined, i.e., Soil 1 plus Soil 2 and this sum compared to the yield from Soil B, i.e., Soil 3 plus Soil 4, Soil A was found to have produced the greater yield. The difference between the two values was 20.26 grams, which was significant at the 5 percent probability level. It is interesting to note that both the topsoil and the subsoil samples of Soil A out yielded their counter parts of Soil B. The greater difference in this instance is found between the two topsoils.

TABLE V

A MULTIPLE RANGE TEST SHOWING SIGNIFICANT DIFFERENCES OF ALFALFA YIELDS FROM SOILS

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error (A)}}{\text{Number of items in soil}}} = .085$

B. Shortest Significant Ranges: ($N_2 = 6$)

		(2)	(3)	(4)
(1% p-level)	p =	5.24	5.51	5.65
	R_p =	.445	.468	.480
(5% p-level)	p =	3.46	3.58	3.64
	R_p =	.294	.304	.309

C. Results:

Soils:	Soil 3	Soil 1	Soil 4	Soil 2
Soil Means:	4.396	4.714	5.675	5.840

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 solid line underscore indicates a similarity of soils at a 1% p-level. A broken line underscore indicates a similarity of soils at a 5% p-level.

Differences in plant yields from soils are more specific in Table V, which indicates that similarities of the soils were in the subsoil and topsoil separations. Either topsoil is shown to be significantly different from either subsoil at both a 5 percent and a 1 percent p-level. The two topsoils are similar at a 1 percent probability, but are significantly different at the 5 percent p-level.

The soils ranked in order of total forage yield would place the two subsoils as first and the two topsoils as second as suitable mediums for plant growth. The sum of dry weight yields from the subsoils was 483.6 grams and from the topsoils 382.6 grams, a difference of 101 grams. When these two yields were compared statistically as shown in Table IV, the resulting F-value was higher than other soil comparisons.

The Effect of Treatments on Yield

The highly significant F-value shown between alfalfa yields due to treatments indicates that the effect of treatments vary, but does not specify the advantage of the use of one over another. More specific observations are made in a multiple range test, Table VI, where similarities and differences between treatments are shown. The most obvious facts presented in this table are that the check treatments and the calcium carbonate treatments were not similar to each other and they were not similar to any of the other treatments. The effects of rock phosphate and of superphosphate when each were applied singly are shown to be similar, but the addition of calcium carbonate to superphosphate gave an increase in yield and showed a significant difference over superphosphate treatment alone at both probability levels. The positive effect of ammonium nitrate additions on alfalfa yields places yields from those

TABLE VI

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

A. Standard Error of Mean = $\sqrt{\frac{\text{Mean Square Error}}{\text{No. items in treatments}}}$ = 0.17

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 =	.476	.501	.518	.530	.540	.547	.554	.559	.564	.571	.578

C. Results

Treatments:	1	2	12	8	3	10	6	7	5	4	9	11	13	14
Means Ranked In Order	1.60	2.564	5.277	5.319	5.40	5.559	5.575	5.578	5.631	5.678	5.910	5.928	5.940	6.217
										– – –	– – –	– – –	– – –	– – –
					– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	
			– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –				

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 soils at a 5% p-level.

treatments near the top of the yield range, but not high enough to become significantly higher than most other treatments.

A comparison of yields from check pots is illustrated in Figure I. It can be readily observed that the yield from Soil 1 is higher in relation to the other three soils. The yield weights of the checks in Table III shows that more than 50 percent of the dry weight yields were taken from the topsoil sample (Soil 1), approximately 25 percent from the other topsoil (Soil 3) and the balance or less than 25 percent from the subsoil (Soil 2). The data does not show a plant yield from the check, Treatment 1, nor the calcium carbonate, Treatment 2, on Soil 4. Plant growth was maintained on these two treatments but the plants were stunted, unthrifty appearing and shorter than the one and one-half inch level above which harvests were taken. This condition was the same in all replications and was considered to be due to soil factors, consequently, yield weights from these two treatments on Soil 4 were considered to be zero.

All treatments showed definite gains in dry weight yields when compared to the yields of their check treatment. When referring to the four soils in the experiment as a unit, the highest significant increases in plant yields were found to be due, in part, to phosphorus application. Statistical F-values shown in Table IV are noticably high for both rock and superphosphate amendments, but a significant difference in yield was not shown between the two. Relative response to the two phosphates are shown in Figures III, IV, V, and VI. If the four soils are examined individually, one will find that yields from rock phosphate, when applied alone, are slightly higher on Soils 1, 2, and 4 than yields from superphosphate alone, and on Soil 3, yields from the two treatments are

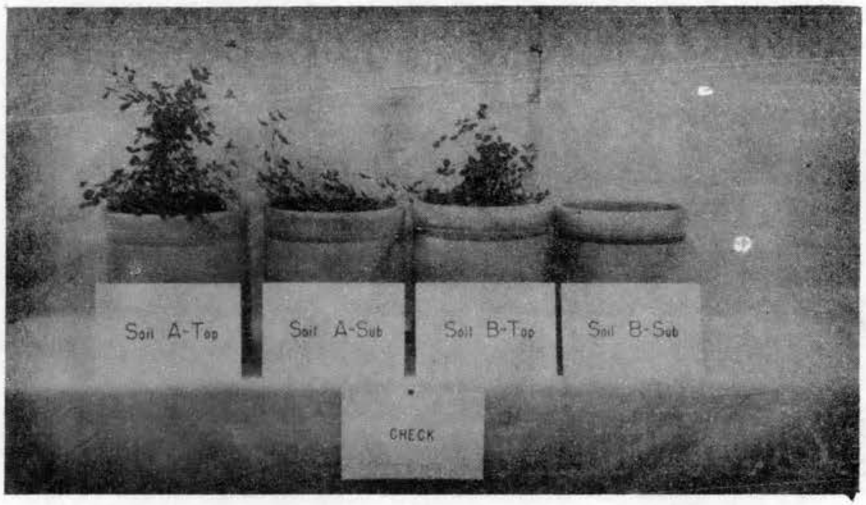

Figure I. Alfalfa growth from the four soils in greenhouse pots under the check treatment four months after date of planting.

Figure II. Alfalfa growth from the four soils in greenhouse pots under the calcium carbonate treatment four months after date of planting.

Figure III. Alfalfa growth in greenhouse pots from soil 1, four months after date of planting, showing the effects of 1,000 pound per acre rock phosphate treatments and 825 pound per acre superphosphate treatments with and without calcium carbonate additions.

Figure IV. Alfalfa growth in greenhouse pots from soil 2, four months after date of planting, showing the effects of 1,000 pound per acre rock phosphate treatments and 825 pound per acre superphosphate treatments with and without calcium carbonate additions.

Figure V. Alfalfa growth in greenhouse pots from soil 3, four months after date of planting, showing the effects of 1,000 pound per acre rock phosphate treatments and 825 pound per acre superphosphate treatments with and without calcium carbonate additions.

Figure VI. Alfalfa growth in greenhouse pots from soil 4, four months after date of planting, showing the effects of 1,000 pound per acre rock phosphate treatments and 825 pound per acre superphosphate treatments with and without calcium carbonate additions.

practically the same. The analysis of variance of yields does not show a significant lime-phosphorus interaction, but the larger F-value of superphosphate versus no superphosphate (453.5) compared to rock phosphate versus no rock phosphate (403.7) might be due to phosphorus - calcium combinations. Yield weights indicate that rock phosphate and superphosphate under the conditions of this experiment have a relative degree of effectiveness, yet, higher yield responses were generally received when calcium carbonate accompanied the superphosphate amendment.

The effects of calcium carbonate on the alfalfa growth from the four soils can be seen in Figure II. The additions of calcium carbonate that were necessary to bring calcium up to 80 percent of the total exchange capacity of the soil seemed quite heavy, yet, the pots of Soil 1 to which lime was the sole treatment had nearly a 40 percent increase in yield over the check, an increase slightly higher than from Treatments 3 and 12, rock phosphate and superphosphate respectively. A statistical comparison of calcium against the no calcium treatments shows a significant positive difference when calcium carbonate was added to the soil. This positive difference was expressed quite markedly in yields from Soils 1 and 3, in which case heavier yields were consistently removed from pots that were supplemented with calcium. Just the reverse is shown on forage produced from the subsoils, especially Soil 4, where the soil treated with rock phosphate plus other fertilizer combinations gave slightly lower yields when calcium carbonate was added. If this lowering of yields was due to a rock phosphate-calcium carbonate combination, it did not apply to the superphosphate-calcium carbonate treatment which produced the second highest yields on this soil grouping. Generally speaking calcium carbonate and associated treatments (Soils 1 and 3)

Figure VII. Alfalfa growth in greenhouse pots on soil 3, four months after date of planting, showing the effects of rock phosphate applied alone and applied in combination with ammonium nitrate, elemental sulful and calcium sulfate.

Figure VIII. Alfalfa growth in greenhouse pots on soil 4, four months after date of planting, showing the effects of rock phosphate applied alone and applied in combination with ammonium nitrate, elemental sulful and calcium sulfate.

produced better alfalfa yields, but if calcium had a positive influence on alfalfa yields on Soil 4 it was probably restricted to the superphosphate Treatment 14 (Refer to Figure VI).

Differences in pot yields, according to the analysis of variance Table IV, due to nitrogen versus no nitrogen treatment are shown to be significant. As illustrated in Figure VIII, the nitrogen-rock phosphate treatment (Soil 4) produced higher yields by 2.3 grams than did the next best treatment. Yields on the same soil (Soil 4) that were ranked third and fourth from the standpoint of dry weight were obtained from nitrogen amendments. The superphosphate-nitrogen combination (Treatment 13 on Soils 1 and 2) produced relatively higher alfalfa yields and showed an increased yield over the superphosphate alone. Yields from pots on topsoil 3 did not indicate any direct beneficial effects from ammonium nitrate applications as shown in Figure VII.

Statistical calculations do not show any significant differences in plant yields from pots treated with a sulfur source compared to the yields from pots without additions of elemental sulfur or calcium sulfate. Furthermore, yield data does not support a significant increase of yields due to one sulfur source over the other. The rank of yields from pots due to treatments in Table VI show that yields from pots having additions of sulfur and calcium sulfate are ranked about the center of the means range, but there is not a sufficient increase in yields from either treatment to be significant. Relative effectiveness of these fertilizers with rock phosphate and nitrogen are shown in Figures VII and VIII.

The Phosphorus Composition of Alfalfa Forage

The effect of fertilizing materials on plant composition is of major concern in plant nutrition studies. Very often the evaluation of fertilizers

TABLE VII

COMPOSITION DATA OF THE
PERCENT TOTAL PHOSPHORUS IN ALFALFA FORAGE

Treatments	Reps.	Soil #1	Soil #2	Soil #3	Soil #4
	1	.1320	.0820	.1080	.1041*
1. Check	2	.1448	.1109	.1171	.1211*
	3	.1160	.0979	.0914	.0986*
	1	.1716	.0778	.1292	.1230*
2. $CaCO_3$	2	.1538	.1278	.1146	.1289*
	3	.1571	.1040	.1287	.1267*
	1	.1605	.1902	.1710	.1972
3. R. Phos.	2	.1716	.1830	.1817	.1740
	3	.1696	.1768	.1992	.1928
	1	.1700	.1212	.1889	.1468
4. R. Phos.	2	.1638	.1376	.1460	.1368
$CaCO_3$	3	.1728	.1328	.1779	.1355
	1	.1627	.1594	.2068	.1760
5. R. Phos.	2	.1672	.1608	.1896	.1568
$CaSO_4$	3	.1588	.1648	.1992	.1838
R. Phos.	1	.1353	.1456	.1560	.1409
6. $CaCO_3$	2	.1705	.1341	.1716	.1211
$CaSO_4$	3	.1638	.1488	.1768	.1424
	1	.1694	.1644	.2192	.1916
7. R. Phos.	2	.1672	.1792	.1992	.1810
Sulfur	3	.1616	.1528	.2068	.1916
R. Phos	1	.1616	.1454	.1655	.1446
8. Sulfur	2	.1728	.1465	.1644	.1015
$CaCO_3$	3	.1424	.1312	.2068	.1368
	1	.1728	.1756	.2043	.1648
9. R. Phos.	2	.1648	.1616	.1953	.1726
Nitrogen	3	.1824	.1688	.1890	.1748
R. Phos.	1	.1704	.1460	.1872	.1977
10. Nitrogen	2	.1876	.1444	.1928	.1904
Sulfur	3	.1588	.1768	.1712	.2112
R. Phos.	1	.1715	.1672	.1824	.1448
11. Nitrogen	2	.1672	.1512	.1600	.1426
Sulfur	3	.1648	.1538	.1704	.1644
	1	.2128	.1684	.2249	.2122
12. S. Phos.	2	.2224	.1820	.2140	.1769
	3	.1998	.1883	.2464	.2128
	1	.2360	.1728	.2204	.1928
13. S. Phos.	2	.2328	.1960	.2056	.2224
Nitrogen	3	.2228	.1723	.2128	.2379
	1	.2800	.2230	.2564	.2359
14. S. Phos.	2	.2560	.1928	.2328	.2743
$CaCO_3$	3	.2488	.1992	.2700	.2296

*Missing data supplied according to G. W. Snedecor; Statistical Methods, Iowa State College Press; p. 268, 1946.

TABLE VIII

ANALYSIS OF VARIANCE OF SPLIT PLOT EXPERIMENT ON PHOSPHORUS COMPOSITION

Source of Variation	Degrees Freedom	Sum of Squares	Mean Square	F. Term
Total	161	.2397369	.0014890	
Reps.	2	.00018	.00009	.23
Soils	3	.02029	.006763	17.34**
Soil A vs Soil B		.12211	.12211	313.10**
Topsoil vs. subsoil		.13584	.13584	348.30**
Main Plot Error	6	.00233	.00039	
Treatments:	13	.17631	.013562	75.55**
Check vs. Others		.04868	.04868	271.19**
Check vs. $CaCO_3$		.002004	.002004	11.16**
Check vs. R.P.		.02966	.02966	165.23**
Check vs. S.P.		.538654	.538654	3000.85**
$CaCO_3$ vs. No $CaCO_3$		.001880	.001880	10.47**
Phos. vs. No Phos.		.091179	.091179	507.96**
R.P. vs. No R.P.		.006631	.006631	36.94**
S.P. vs. No S.P.		.129439	.129439	721.10**
R.P. vs. S.P.		.043012	.043012	239.62**
S. Source vs. None		.00019	.00019	1.05
S. vs. $CaSO_4$		.000256	.000256	1.42
N. vs. No N.		.000093	.000093	.51
Lime-Phos. interaction		.01506	.01506	83.89**
Treatment x Soils	39	.02303	.0005905	3.28**
Experimental Error	98	.01759	.0001795	

**Denotes significance at a 1% probability level.

is based on yield alone and composition studies are neglected. The organic and elemental composition of alfalfa are major criteria according to some authors (7,47) in judging its quality as a feed for livestock. It is of general knowledge that plant yield and elemental composition are not analogous in all cases, and that the makeup of plants are affected by a number of factors.

The Effect of Soils on Phosphorus Composition

Differences in soils according to Beeson (7) are an important factor contributing to the elemental composition of plants. Dennis (15) furnished evidence that interactions between treatment and soil horizon resulted in different rates of phosphorus availabilities between horizons.

The analysis of variance of phosphorus composition, Table VIII, shows that the four soils were important factors contributing to significant differences in phosphorus composition of plant material. The percent total phosphorus composition of the alfalfa forage from individual soils are listed in Table VII. The sums of the total phosphorus percentages of the alfalfa from each soil were compared and were found to be statistically different. The soils rank in order, from the highest to the lowest sum of the phosphorus percentages of the alfalfa, was as follows: Soil 3 (7.751), Soil 1 (7.468), Soil 4 (7.111), and Soil 2 (6.515).

At this point it is interesting to note that the rank of soils according to phosphorus percentages is in a completly reversed order of soils ranked according to yields.

The analysis of significant differences in phosphorus composition due to the four soils was extended into a comparison of Soil A versus Soil B. Significant differences between Soils A and B due to variation of total phosphorus composition of plants is shown in Table VIII. The

TABLE IX

A MULTIPLE RANGE TEST SHOWING SIGNIFICANT DIFFERENCES OF TOTAL PHOSPHORUS COMPOSITION OF ALFALFA YIELDS FROM SOILS

A. Standard Error of Mean = $\sqrt{\frac{\text{Mean Square Error (A)}}{\text{Items in Soil}}} = .00305$

B. Shortest Significant Ranges: ($N_2 = 6$)

		(2)	(3)	(4)
(1% p-level)	p =	5.24	5.51	5.65
	R_p =	.0159	.0168	.0172
(5% p-level)	p =	3.46	3.58	3.64
	R_p =	.0105	.0109	.0111

C. Results:

Soils:	Soil 2	Soil 4	Soil 1	Soil 3
Soil Means:	.1551	.1693	.1778	.1845
	————	————		
		————	————	————
			- - - -	- - - -
		- - - -	- - - -	

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 solid line underscore indicates a similarity of soils at a 1% p-level. A broken line underscore indicates a similarity of soils at a 5% p-level.

total sum of phosphorus percentages of the alfalfa grown on Soil B was 14.8 and the total from Soil A was 13.9. Both soils comprising Soil B, that is, Soil 3 and Soil 4, were individually higher in total phosphorus percentages than were the comparable soils (Soils 1 and 2) of Soil A.

To further clarify the significant differences between soils, a statistical comparison was made between the subsoil and the topsoil. The analysis of variance table on phosphorus composition furnished evidence of significance between the two soils at the one percent probability level. The sum of total phosphorus percentages of alfalfa grown on the topsoils (Soil 1 and Soil 3) was 15.2, and the comparable sum of the subsoils (Soil 2 plus Soil 4) gave a much lower value, 13.6. These figures indicated a slightly greater difference between topsoil and subsoil comparisons than between differences due to locations from which the soils were removed.

A multiple range test of the soils (Soils 1, 2, 3, 4,) Table IX, based on the phosphorus composition of alfalfa forage produced, shows that any one of the soils having a mean between a range of 0.1845 to 0.1673 would be similar to Soil 3 at the one percent p-level. Soils in this range were Soils 3, 1, and 4. Less similarity existed between the four soil means at the five percent p-level. The topsoils, 1 and 3, were still similar and Soil 4 was similar to Soil 1 but not to Soil 3. The mean of Soil 2 was different from all the others at the five percent p-level.

These figures lend increased support to other data showing differences in the uptake of phosphorus by alfalfa due to surface and subsurface soil separations.

TABLE X

A MULTIPLE RANGE TEST SHOWING THE SIGNIFICANT DIFFERENCE OF PHOSPHORUS COMPOSITION OF ALFALFA DUE TO TREATMENTS

A. Standard Error of Mean = $\sqrt{\frac{\text{Mean Square Error}}{\text{No. items in treatments}}}$ = .00387

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 =	.0108	.0114	.0118	.0120	.0123	.1024	.0126	.0127	.0128	.0130	.0131

C. Results

Treatments:	1	2	6	8	4	11	5	9	10	3	7	12	13	14
Means Ranked In Order	.1103	.1286	.1505	.1516	.1525	.1616	.1738	.1772	.1778	.1806	.1820	.2050	.2103	.2415

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 soils at a 5% p-level.

The Effect of Treatments on Phosphorus Composition

When treatments were considered as a source of variation of phosphorus composition, Table X shows high significance at the one percent probability level. The specific relation of treatments shows that at the five percent p-level the check treatment and the calcium carbonate treatment were not similar and were different from all other treatments. An important factor is the similarity of all rock phosphate-calcium carbonate combinations. All these treatments grouped together at the lower mean scale range.

There was a difference noted between the rock phosphate treatments with calcium and those without calcium additions, perhaps indicating a negative response of calcium carbonate to the availability of phosphorus in rock phosphate. The positive influence of superphosphate is clearly shown from the position of those treatments on the upper end of the mean range scale. The addition of calcium carbonate to superphosphate make Treatment 14 positively significant over all treatments.

The effect of phosphorus treatments on the phosphorus content of the alfalfa forage is shown to be of considerable importance in Table VIII. Although application of phosphates appeared to be a key factor in phosphorus assimilation by the plant, the two forms used were not equally effective and the comparison of rock phosphate versus superphosphate showed a significant positive effectiveness of superphosphate as a phosphorus source. Both phosphorus sources were significant in their effect on the phosphorus content of the plants grown, but their F-values were numerically different. Probably the highest statistically significant figure of the entire experiment, an F-value 3,000.8, was the result of comparing the superphosphate treatment twelve to the check treatment.

Phosphorus composition of alfalfa from individual soils showed that superphosphate treatments twelve, thirteen, and fourteen had greater effect than rock phosphate on phosphorus content of the plants. One exception to this generality was shown in the phosphorus composition of alfalfa grown on Soil 2, treatment three (rock phosphate alone), where the effect of rock phosphate on phosphorus composition was surpassed only by treatment fourteen, the superphosphate-calcium carbonate application.

When statistical comparisons concerning the effectiveness of calcium carbonate were made, its relationship to the check shows an increase of phosphorus content in the plants due to the calcium carbonate treatment. The influence of calcium carbonate was most apparent in Soil 1, (topsoil) treatment two, where the total phosphorus composition of alfalfa in these pots was relatively high. There was some indication of a slight increase of phosphorus uptake from Soil 1 treated with a rock phosphate-calcium carbonate combination over the rock phosphate treatment alone. The benefit of calcium carbonate when used with rock phosphate was largely confined to Soil 1 which in part might be explained by a treatment-soil interaction. Table VIII also shows a significant lime-phosphorus interaction, and the bulk of these data shows that plants from pots treated with rock phosphate and associated fertilizers were higher in phosphorus than those pots to which calcium was added. This generalization was not found to occur in treatment fourteen, in which case lime and phosphorus worked in harmony and the phosphorus uptake was relatively high.

No significant statistical evidence was found to support a difference in the phosphorus composition of alfalfa due to sulfur, calcium sulfate or ammonium nitrate fertilization in the manner they were used in this experiment.

TABLE XI

COMPOSITION DATA OF THE
PERCENT TOTAL NITROGEN IN ALFALFA FORAGE

Treatments		Reps.	Soil #1	Soil #2	Soil #3	Soil #4
		1	3.641	2.874	3.337	3.145*
1.	Check	2	3.890	3.264	3.727	3.488*
		3	3.532	3.337	3.373	3.275*
		1	4.002	2.460	3.398	3.148*
2.	$CaCO_3$	2	3.812	3.410	3.727	3.510*
		3	3.544	3.483	3.629	3.413*
		1	3.410	3.532	3.727	3.530
3.	R. Phos.	2	3.434	3.751	3.897	3.443
		3	3.532	3.727	3.921	3.483
		1	3.495	3.069	3.763	3.337
4.	R. Phos.	2	3.520	3.252	3.495	3.008
	$CaCO_3$	3	3.483	3.349	3.788	3.179
		1	3.739	3.398	3.897	3.362
5.	R. Phos.	2	3.666	3.702	3.885	3.410
		3	3.544	3.605	3.593	3.483
	R. Phos.	1	3.130	3.240	3.581	3.301
6.	$CaCO_3$	2	3.702	3.178	3.848	3.203
	$CaSO_4$	3	3.434	3.227	3.593	3.301
		1	3.751	3.422	3.714	3.751
7.	R. Phos.	2	3.812	3.544	3.800	3.373
	Sulfur	3	3.532	3.568	3.568	3.556
	R. Phos.	1	3.637	3.386	3.434	3.264
8.	Sulfur	2	3.483	3.398	3.459	3.021
	$CaCO_3$	3	3.483	3.203	3.800	3.239
		1	3.771	3.386	3.788	3.301
9.	R. Phos.	2	3.581	3.361	3.812	3.288
	Nitrogen	3	3.995	3.386	3.775	3.129
	R. Phos.	1	3.922	3.142	3.520	3.593
10.	Nitrogen	2	3.981	2.947	3.678	3.386
	Sulfur	3	3.581	2.972	3.544	3.568
	R. Phos.	1	3.746	3.483	3.544	3.337
11.	Nitrogen	2	3.702	3.581	3.507	3.349
	Sulfur	3	3.508	3.532	3.544	3.325
	$CaCO_3$					
		1	3.739	2.947	3.934	3.922
12.	S. Phos.	2	3.739	3.727	3.715	3.800
		3	3.520	3.812	3.934	3.629
		1	3.532	3.556	3.848	3.727
13.	S. Phos.	2	3.775	3.775	3.775	3.751
	Nitrogen	3	3.666	3.763	3.897	3.934
		1	3.666	3.617	3.921	3.788
14.	S. Phos.	2	3.666	3.605	3.934	3.629
	$CaCO_3$	3	3.702	3.556	3.970	3.861

*Missing data supplied according to G. W. Snedecor; Statistical Methods, Iowa State College Press; p. 268, 1946.

TABLE XII

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

Source of Variation	Degrees Freedom	Sum of Squares	Mean Square	F. Value
Total	161	11.09124		
Reps.	2	.11670	.05835	.7377
Soils	3	2.88656	.96218	12.16**
Soil A vs. Soil B		.12640	.12640	1.59
Topsoil vs. Subsoil		2.75816	2.75816	34.87**
Main Plot Error	6	.47454	.07909	
Treatments:	13	2.59219	.19939	7.83**
Check vs. Others		.24853	.24853	9.76**
Check vs. $CaCO_3$		.01777	.01777	.6985
Check vs. R.P.		.26125	.26125	10.26**
Check vs. S.P.		.52070	.52070	20.46**
$CaCO_3$ vs. No $CaCO_3$		.27620	.27620	10.85**
Phos. vs. No Phos.		.51600	.51600	20.28**
R.P. vs. R.P.		.06064	.06064	2.38
S.P. vs. No S.P.		.99600	.99600	39.15**
R.P. vs. S.P.		.80941	.80941	31.81**
S. Source vs. None		.00768	.00768	.0301
S. vs. $CaSO_4$		.00065	.00065	.0025
N. vs. No N.		.00202	.00202	.0079
Lime-Phos interaction		.39114	.39114	15.37**
Treatments x Soils	39	2.52853	.064834	2.54**
Experimental Error	98	2.49272	.02544	

**Denotes significance at a 1% probability level.

The Nitrogen Composition of Alfalfa Forage

The Effect of Soils on Nitrogen Composition

The analysis of variance of factors leading to differences in nitrogen composition of alfalfa forage produced in this experiment (Table XII) shows that differences caused by soils were significant at the one percent probability level. If the figures representing percent nitrogen composition in plant material are totaled within each soil the amounts representing each soil and their rank in order would be as follows: Soil 3 (155.5), Soil 1 (152.9), Soil 4 (144.5), and Soil 2 (142.5). It is interesting to note that the four soils ranked in this order are in the reverse of soils ranked according to yield.

A further statistical breakdown of soils, or Soil A versus Soil B, did not show a significant difference in nitrogen content. From the figures above, Soil 1 plus Soil 2 equals 295.5 and Soil 3 plus Soil 4 equals 300.1. The difference between the two is only 4.6. This similarity of the summed percentages of nitrogen in Soils A and B reflects doubt that soil type was the major factor of differences between the four soils studied.

Table XII shows that the major difference in nitrogen content of alfalfa forage from soils was between subsoil and topsoil comparisons. The sum of nitrogen percentages for topsoils (1 plus 3) is approximately 308.5 and that for subsoils (2 plus 4) approximately 287.0. Difference between the two soil horizons is a much larger figure than that between Soil A and Soil B. These figures may indicate the relatively favorable effect of topsoil over subsoil when nitrogen composition of plant material is used as a measure of comparison. An evaluation of differences in the

TABLE XIII

A MULTIPLE RANGE TEST SHOWING SIGNIFICANT DIFFERENCES BETWEEN TOTAL NITROGEN COMPOSITION OF ALFALFA FORAGE FROM SOILS

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error (A)}}{\text{Items in Soil}}} = .0434$

B. Shortest Significant Ranges: ($N_2 = 6$)

		(2)	(3)	(4)
(1% p-level)	$p =$	5.24	5.51	5.65
	$R_p =$	.2274	.2391	.2452
(5% p-level)	$p =$	3.46	3.58	3.64
	$R_p =$	.1501	.1553	.1579

C. Results:

Soils:	Soil 2	Soil 4	Soil 1	Soil 3
Soil Means:	3.3935	3.4414	3.6428	3.7046

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 solid line underscore indicates a similarity of soils at a 1% p-level. A broken line underscore indicates a similarity of soils at a 5% p-level.

TABLE XIV

A MULTIPLE RANGE TEST SHOWING THE SIGNIFICANT DIFFERENCES OF NITROGEN COMPOSITION OF ALFALFA DUE TO TREATMENT

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .046$

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 =	.1288	.1357	.1403	.1435	.1462	.1481	.1499	.1513	.1527	.1545	.1564

C. Results

Treatments:	4	6	8	1	2	10	11	9	5	3	7	12	14	13
Means Ranked In Order	3.394	3.394	3.400	3.406	3.406	3.486	3.513	3.547	3.607	3.615	3.615	3.701	3.742	3.749
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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 soils at a 5% p-level four soils is shown in Table XIII. At the 5 percent p-level the means of the two subsoils are considered similar. The same is true of the two topsoils, but there is a significant difference between topsoil and subsoil samples.

The Effect of Treatments on Nitrogen Composition

The effect of treatments on nitrogen composition of alfalfa forage is shown to be significant at the 1 percent probability level as shown in Table XIV. It is interesting to note that both the rock phosphate and the superphosphate treatments increased the nitrogen content of the plant material significantly over the check treatment. The positive effect of phosphorus on nitrogen content of forage is substantiated by the comparison of phosphorus treatments three, four, twelve, and fourteen versus the no phosphorus treatments one and two. Although both phosphate fertilizers tended to influence the plant's content of nitrogen, the two did not show equal effectiveness. The highly significant F-value resulting when the two phosphorus sources with their associated amendments were compared indicated that superphosphate had an advantage over rock phosphate.

The direct effect of calcium carbonate as a treatment in the experiment was not shown. Treatment two in which calcium carbonate was applied increased the percentage of nitrogen to a slight degree over that of the check treatment. This increase was not found to be significant after a comparison of the two had been made statistically. Calcium carbonate seemed to function clearly in a lime-phosphorus interaction and apparently not in a lime-nitrogen interaction. The beneficial effect of rock phosphate on nitrogen composition was significant but when a comparison was made between rock phosphate and no rock phosphate a significant difference was not shown. In the latter comparison the only difference was that calcium carbonate additions entered the comparison and may have altered the influence of the rock phosphate.

The effects of other fertilizing materials was not shown to be significantly effective on the nitrogen composition of the plant material.

The multiple range, Table XIV, shows much similarity of treatment means. Treatment 13, superphosphate plus nitrogen combination, is ranked at the upper limits of the means scale and is significantly different from treatments four, six, eight, and one at the lower end of this scale.

SUMMARY AND CONCLUSIONS

This thesis reports the results of a greenhouse experiment undertaken at 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 randomally arranged in a 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. After a four month growing period, plants were harvested and analyzed in the laboratory. The following conclusions are an evaluation of soils and fertilizing treatments based on alfalfa yield and alfalfa composition data.

Although Soil A and Soil B were similar in many visible profile characteristics, the responses of each varied appreciably. An evaluation of alfalfa forage yield and composition by statistical methods showed that the soil was a major cause of differences in the alfalfa plant top yields and the percent phosphorus and percent nitrogen composition. Larger significant yields were produced on Soil A. Both the topsoil and the subsoil samples of Soil A produced more alfalfa forage than the related separations of Soil B. Dry weight yields of plant material from the two subsoils were higher than from the two topsoils. Soil 2 produced the largest yield followed in descending order by Soil 4, Soil 1, and Soil 3.

The percent phosphorus composition of plant material from Soil B was found to be significantly greater than that from Soil A. A comparison of topsoil and subsoil separates showed the topsoils to be more effective in increasing phosphorus composition of the plants. The order of soils according to phosphorus percentages was in reverse order of soils ranked according to yields.

A comparison of nitrogen percentages of alfalfa grown on Soil A and Soil B were not significantly different, however, variation between the topsoil and subsoil was the chief factor which caused significant differences in nitrogen composition. The total nitrogen percentages of plant material from the topsoil were greater than those from the subsoil. Alfalfa yields and composition percentages showed a highly significant interaction between soils and treatments.

The effects of treatments in producing significant differences between plant yields, total nitrogen content and total phosphorus content was evident in each instance. 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. The comparison of yields from the two phosphate sources when they were applied singly did not show a significant difference. A positive increase in yield from the two topsoils was obtained by calcium carbonate additions. On Subsoil 4 calcium carbonate treatment suppressed the yields of the rock phosphate treatments. The beneficial effect of superphosphate on yields was increased with calcium carbonate treatments. Ammonium nitrate fertilization was very effective in increasing plant yields. Increased yields from elemental sulfur or calcium sulfate applications were not significant.

The percent phosphorus composition of the plant material was affected specifically by the phosphorus treatment. The highest percentage of phosphorus in plant material was from the superphosphate treatments. There was an indication of lime-phosphorus interaction. These data show that the presence of calcium carbonate decreased the uptake of phosphorus from the rock phosphate treatment, but that the phosphorus content of plants grown on the superphosphate plus calcium carbonate treatments was significantly higher than from all others. Applications of elemental sulfur, calcium sulfate and ammonium nitrate were shown to be not significantly effective in increasing the plant's phosphorus composition.

Both phosphate forms increased the nitrogen content of the plant material over the check treatment, but the two were not equally effective when combined with other fertilizer amendments. There was a lime-phosphorus interaction on the nitrogen percentage from superphosphate and rock phosphate. Calcium carbonate, when accompanying rock phosphate, depressed the effectiveness of the phosphate. The effectiveness of superphosphate was increased by calcium carbonate. Elemental sulfur, calcium sulfate, and ammonium nitrate did not show a significant effect on the nitrogen composition of plant material.

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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 XV

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	1,2 vs. 3,4	1
Topsoil vs. Subsoil	1,3 vs. 2,4	1
Reps. x Soils (Error A)		6
Treatments:		13
Check vs Others	1 vs. 2-14	1
Check vs. $CaCO_3$ alone	1 vs. 2	1
Check vs. Rock Phos. alone	1 vs. 3	1
Check vs. Superphos. alone	1 vs. 12	1
$CaCO_3$ vs. No $CaCO_3$	1,3,5,7,10,12 vs. 2,4, 6,8,11,14.	1
Phos. vs. No Phos.	1,2 vs. 3,4,12,14	1
Rock Phos. vs. No R. Phos.	1,2 vs. 3,4	1
Superphos. vs. No S. P.	1,2 vs. 12,14	1
Rock Phos. Vs. Superphos.	3,4,9 vs. 12,13,14	1
S. source vs. None	3,4,9 vs. 5,6,7,8,10	1
S. vs. $CaSO_4$	5,6 vs. 7,8	1
N. vs. No N.	3,7,8,12 vs. 9,10,11,13	1
Lime x Phos. interaction	1,4 vs. 2,12	1
Treatments vs. Soils		39
Experimental Error		104

VITA

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