EFFECT OF ROCK PHOSPHATE, SUPERPHOSPHATE, AND LIME ON YIELD AND COMPOSITION OF ALFALFA GROWN ON SIX OKLAHOMA SOILS

By

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I INTRODUCTION

Phosphorus has been recognized as the limiting soil fertility factor for crop production in Eastern Oklahoma. A profitable agricultural industry cannot be developed or maintained on soils of this area without the liberal use of phosphorus fertilizers (20, 22).[1] Harper (21) has shown that the use of both rock phosphate and superphosphate increased clover yields on soils of Eastern Oklahoma. Profit or loss on soils of this area is directly related to phosphorus fertilization, therefore it would be advantageous if a cheaper source of phosphate fertilization could be found for this area.

Alfalfa is one of the most important hay crops of Oklahoma in terms of both yield and feeding value, and it is considered as one of the most efficient utilizers of phosphorus from rock phosphate.

The inherent physical and chemical characteristics of a soil play a very important part in the utilization of a fertilizer amendment by a plant. The relationship of soils, plant, and fertilizers offers many avenues for profitable research. The proposed objectives of this experiment were to determine the relative efficiency of rock phosphate and superphosphate as to yield and chemical composition of alfalfa, and to determine if any relationship existed as to treatment response between soils.

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

II REVIEW OF LITERATURE

Phosphorus is the major limiting soil fertility factor for crop production in Central and Eastern Oklahoma. Harper (20, 22) reported that fifty percent of the soils in Eastern Oklahoma contained less than fifty pounds of easily soluble phosphorus per acre. He concluded that in many cases a profitable agricultural industry could not be developed or maintained without the liberal use of this important element. Chaffin (7) also discussed the need for replenishing the phosphorus supply of Oklahoma soils. Several investigators (29, 34) report that phosphorus fertilization is complicated by the variabilities of soils, crops, climatic factors, and cultural practices. The three soil phenomena of fixation, immobilization, and mineralization determine the utilization efficiency of applied phosphorus fertilizers (29). Only one-half to one-tenth of the phosphorus supplied by phosphate fertilizers is utilized by the plant (9).

The comparative phosphorus supplying ability of rock and superphosphate has long been a controversial problem. Several investigators have found superphosphate to be a more readily available source of phosphorus than rock phosphate (38, 51, 35). Roberts (43) reported rock phosphate was equal to superphosphate on some soils whereas on other soils it was inferior to superphosphate. Fine (15) reported no significant difference between rock and superphosphate as determined by alfalfa hay yields grown on a Bolivar very fine sandy loam. Weeks (55) found rock phosphate produced greater crop response than superphosphate on a sixteen year fertility field experiment. Phibbs (41) stated that a comparison of alfalfa yields from the two phosphorus sources when they were applied singly did not show significant differences in yield.

Albrecht (1) reported the amount of phosphorus removed by a crop increased as larger amounts of lime was added to the soil. The addition of phosphorus was not as effective for increasing the phosphorus uptake as the addition of lime. Effective recovery of applied phosphorus was assured if a liberal supply of calcium was present in the soil. Addition of lime was a matter of supplying calcium to the plant effectively and therefore aided the plant in securing its phosphorus requirement. The purpose of liming according to Albrecht is not only to modify the hydrogen ion concentration of the soil, but to increase phosphorus availability. MacLean (31) found liming to the neutral point, or slightly above, increased the amount of soil phosphorus available to alfalfa. Several investigators (55, 42, 24) report that superphosphate plus lime will produce higher crop response than rock phosphate plus lime. Rock phosphate plus lime has a depressing effect upon the forage yields of legumes (28, 54, 41, 38) according to several investigators. Other investigators (31, 32, 21) have reported calcium carbonate increased forage yields.

The combination of rock phosphate and superphosphate influences yield more than either rock phosphate or superphosphate alone. MacLean (35) reported an increase in alfalfa forage yield due to this mixture. He attributed the response to the initial availability of superphosphate and the residual effect of rock phosphate. Jones (28) reported, however, that a mixture of superphosphate-rock phosphate plus lime resulted in forage yield of fescue grass that was less than the superphosphate-lime treatment. Both of these treatments produced more fescue forage than did either rock phosphate plus lime or rock phosphate alone. Murdock (36) stated that a rock phosphate-superphosphate mixture was beneficial for most crops. The amount of rock phosphate required to produce maximum results was considerably greater than the superphosphate in the mixture. When rock phosphate and superphosphate were mixed in equal amounts the crop response due to this treatment was less than rock phosphate or superphosphate applied singly. Phosphorus and calcium relations in plants have not furnished evidence that utilization of calcium and phosphorus from the same source is a positive factor for increasing the availability of rock phosphate (2).

Many plants have been found to differ in their ability to obtain and utilize rock phosphate (13), and alfalfa is one of the more efficient. Alfalfa has long been recognized as an outstanding hay plant in terms of both yield and feeding value (5). DeTurk (12) concluded from his studies that alfalfa could utilize the phosphorus from rock phosphate directly. Harper's (20) results were contrary to this report and he concluded that alfalfa was not a vigorous feeder on insoluble phosphorus compounds under Oklahoma conditions, however, rock phosphate was more readily available to legumes than to the grasses. Root excretion theories, elemental balance theories, and microbiological interactions might explain this difference (16). The cation exchange capacity of the alfalfa root is from three to four times as great as those of red top or reed canarygrass. This may explain the difference between grasses and legumes in the utilization or rock phosphate (33). Plants which have a high calcium content also have a high feeding power for the phosphorus in rock phosphate (3, 19). Collodial systems which exhibit low bonding energies for calcium will possess a high capacity to solubilize rock phosphate according to Graham (19). The relative driving energies of different collodial systems might determine the availability of phosphorus (19). Plants which are poor utilizers of rock phosphate would benefit by growing in conjunction with a strong feeder according to Drake and Steckel (13). Legumes, unlike other plants, are not appreciably retarded in their uptake of phosphorus from rock phosphate by the presence of limestone (12).

Troug (53) believes there is a definite relationship between pH of the soil and the availability of rock phosphate and superphosphate, and in order for rock phosphate to be available, the soil pH must be in the acid range. If the soil is limed to a pH 7.0 or higher the solubility of the rock phosphate is impaired (42, 53, 46). Truog (53) believes there must be a compromise between the pH most favorable for rock phosphate availability and the lime requirement of the plant to be grown. DeTurk (12) reported that without lime the soil-building legumes grown on acid soils would die. Bradfield (6) reported soils have a great ability to retain phosphorus ions over a wide range of reactions and concentrations. He believed that this was due to several different mechanisms, which under normal soil conditions overlap. At pH 4.5-7.5 much of the phosphorus appears to be fixed on the surface of the clay particles, and from pH 6.0-10.0 much of it is fixed by divalent cations. Copeland (9) found that fixation was greater in acid soils while phosphorus availability increased at neutrality on a given soil type. Truog (53) reported at a pH 6.5-7.0 conditions were most favorable for phosphorus availability. At pH 6.5 lime is sufficiently abundant to keep a considerable portion of the phosphorus in the form of dicalcium phosphate which is soluble in carbonic acid, and hence, readily available. Calcium bicarbonate is formed at a pH 7.5 and the phosphorus becomes less available.

Iron, aluminum, and calcium are largely responsible for the fixation of phosphorus in some soils (30, 13, 45, 10), and all neutral salts probably cause the solubility of soil phosphate to decrease. In the case of salts with a common anion, the depressing effect of the cation on solubility of soil phosphate increased in the order of the lyotropic series: Na, < K, < Mg, < and Ca (30). The nature of the cation on the clay should determine the extent and energy of adsorption. Hydrous oxides of iron and aluminum on the soil particle surface are capable of retaining large amounts of phosphate. This reaction may be involved in phosphorus retention or fixation by soils (17, 45). Copeland (9) states from one-half to one-tenth of the phosphorus applied as a phosphate fertilizer is never absorbed by the plant. Hinkle (25) reports unavailable tricalcium phosphate is formed in highly calcareous soils.

Phosphorus retention by the clay complex has been studied by several investigators. Murphy (37) states that there is a fixation of phosphorus by the alumino-silicates. Graham (19) found soils containing kaolin clays in small amounts will represent an unfavorable environment for the utilization of rock phosphate; therefore, the availability of phosphorus is related to the relative driving energies of the different collodial systems. Phosphorus in a calcium saturated montmorillonite clay was fixed as a calcium phosphate complex, and not by a H_2PO_4-Ca-clay bonding. Clays which were saturated with sodium, potassium, and magnesium fixed only small amounts of phosphorus against water extraction (45). Perkins (40) reported muscovite and montmorillonite produced maximum fixation at the lower pH ranges. Montmorillonite was found to fix five times as much phosphorus as kaolinite.

Olsen (39) states a close relationship exists between soils series, pH, and soluble phosphorus in fifteen major soil series in Nebraska ranging from a fine sand to a silty clay texture. Two Oklahoma soils classified as Bethany silt loam with very similar profiles and chemical characteristics reacted the same (38, 41). Smith (49) reported two soils of the Illiot-Ashkum and Swygert-Bryce Association were fundamentally similar in their characteristics. The Joliet and Kewanee soils of this association differed in their response to rock phosphate. The permeability of the profiles to roots was determined to be the major factor determining crop response to rock phosphate on these soils. A Bethany silt loam from two different locations of Central Oklahoma was used in a greenhouse fertility study (38) and from eight harvest yields of alfalfa there were no significant differences between the top soils or the subsoils of these two profiles. There was, however, a significant difference between soils for nitrogen, phosphorus, and potassium content of the plants. Harper (20) found phosphorus deficiencies in Eastern Oklahoma were closely related to upland and bottomland soils. The bottomland soils were not found to be as deficient in phosphorus as the upland soils. Dennis (11) found a difference in phosphorus uptake by alfalfa from four Eastern Nebraska soils. The order of availability of each soil was different.

The efficiency of utilization of rock phosphate and superphosphate is increased by the presence of organic matter. The activity of organic matter in making soil phosphorus available is attributed to certain metabolic products of microbiological decomposition which form complex molecules with iron and aluminum (10). Garman (18) worked with Oklahoma soils, and he found fifteen to eighty-five percent of the soil phosphorus was in organic compounds, and this phosphorus was utilized by plants at a rate equal to that of the inorganic phosphates.

Fineness of grind is a very important factor in the utilization of rock phosphate. Phosphorus from rock phosphate becomes more available with increasing fineness of grind, because of the increased surface exposed to weathering by the soil solution (42, 44, 2). Jones (27) reported defluorinated rock phosphate produced higher crop yields than ordinary rock phosphate. Pierre (42) reported that an increase in the fluorine content of rock phosphate reduced its availability.

Rock phosphate has a longer residual effect than does superphosphate. Rock phosphate on several long time experiments continued to produce maximum yields, whereas the superphosphate treatments caused a decline in yields with time (55, 48, 42).

Leaching of the soil profile renders the phosphorus in rock phosphate available. Leaching removes calcium bicarbonate and soluble calcium salts, thus making the rock phosphate more readily available (3). Phosphorus uptake is closely related to water solubility, whereas calcium uptake shows a negative relationship with water (52).

McLean (35) conducted a greenhouse phosphorus fertility experiment with alfalfa as the test plant. He used 1500 pounds per acre of rock phosphate, 900 pounds per acre of superphosphate, and 450 pounds per acre of superphosphate mixed with 750 pounds per acre of rock phosphate as the three fertility treatments. The superphosphate treatment produced the greatest amount of alfalfa forage and rock phosphate-superphosphate mixture, rock phosphate, and check followed in descending order. Phosphorus percentages in the alfalfa forage were as follows in descending order: superphosphate, rock phosphate-superphosphate mixture, rock phosphate, check. Potassium percentages as affected by the above fertility treatments were as follows in descending order: superphosphate, rock phosphate, rock phosphate-superphosphate mixture, and check. Magnesium percentages ranked in descending order were as follows: superphosphate, rock phosphate, check, and rock phosphate-superphosphate mixture. All elements other than phosphorus, such as nitrogen, potassium, calcium, and trace elements, had been added to all pots in sufficient amounts to produce maximum alfalfa growth. The percentages of phosphorus and calcium in buckwheat were reported by Ames (2). The fertility treatments in his experiment ranked from the highest to the lowest as they affected the phosphorus content of the plants were as follows: rock phosphate, superphosphate plus lime, superphosphate, rock phosphate plus lime, calcium carbonate, and no treatment. The calcium percentages of buckwheat as affected by the fertility treatments ranked in descending order were: calcium carbonate, rock phosphate plus lime, rock phosphate, no treatment, superphosphate plus lime, and superphosphate. Nickols (38) reported no significant difference between rock phosphate at 100 pounds per acre and superphosphate at 825 pounds per acre on alfalfa forage yields; however, superphosphate showed a significant increase over rock phosphate in phosphorus uptake by the plant. Calcium carbonate treatment increased the amount of calcium taken up by the plant, and there was a beneficial interaction between superphosphate and lime, which increased the yields significantly above all other treatments in this greenhouse study. Phibbs (41) reported no significant difference between alfalfa hay yields from superphosphate plus lime treatment and rock phosphate plus lime treatment. The alfalfa yields as affected by treatment ranked in descending order were as follows: superphosphate plus lime, rock phosphate plus lime, rock phosphate, superphosphate, calcium carbonate, and check. Rock phosphate produced a significant yield increase over superphosphate. Suerphosphate plus lime gave significantly higher phosphorus uptake by alfalfa than all other treatments. The phosphorus content ranked in descending order of treatment were: superphosphate plus lime, superphosphate, rock phosphate, rock phosphate plus lime, calcium carbonate, and check. There was no significant difference in nitrogen content of alfalfa between superphosphate plus lime, superphosphate, and rock phosphate.

Several investigators (3, 54) have reported nitrogenous fertilizers increased the availability of phosphate fertilizers. Cheaney (8) states that the fertility treatment which results in the greatest amount of phosphorus in the plant would also show the greatest amount of nitrogen.

The solubility of phosphorus in fertilizer materials furnishes a comparative measure of their availability and effectiveness, but unfortunately solubility and availability are not synonymous terms (2). It requires from 2-7 times more P_2O_5 supplied as rock phosphate to produce a crop response equal to an equivalent amount of P_2O_5 superphosphate (28, 42, 44, 36).

III METHODS AND MATERIALS

The data presented in this thesis were obtained from a greenhouse study. The objectives of this experiment were twofold. The first objective was to determine the relative response to fertilizer treatments. The second objective was to determine if any relationship existed as to treatment response between soils. Plant yield and composition were used as criteria for these determinations.

Description of the Soils Studied

The Eastern one-half of Oklahoma was divided arbitrarily into three geographical regions. From each of these geographical regions two dissimilar soils were selected for the experiment. One soil from each region represented a prairie soil which had a silt loam A horizon and a clayey B horizon, whereas the other soil of each region was a formerly wooded soil which had a sandy loam A horizon and a sandy clay loam B horizon. It was thought that the nutrient content of the former wooded soils would be consistantly lower than the prairie soils. These soils had been under cultivation for approximately fifty years. From the Central region of Eastern Oklahoma a Kirkland loam, referred to as "Soil A", was selected as the prairie soil, and Stephenville fine sand, referred to as "Soil B", was selected to represent the wooded soil of this region.[1] From the Northeast region of Eastern Oklahoma a Parsons silt loam, referred to as "Soil C", was selected as the prairie soil, and Linker

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Profile descriptions furnished by H. M. Galloway, Assistant Soil Surveyor (Coop. U.S.D.A., and S.C.S.) Soil Correlator; Oklahoma. (Refer to Appendix) fine sandy loam, referred to as "Soil D", was selected as the wooded soil for this region. From the Southeast region a Wilson loam, referred to as "Soil E", was selected to represent the prairie soil, and Bowie loamy fine sand, referred to as "Soil F", was selected as the wooded soil of this region. The soil samples were taken in September, 1956.

Preparation of Soils for Pot Culture

Each soil was mixed thoroughly and sieved through a quarter-inch hardware cloth screen and allowed to dry. After the soils had dried, 9,500 grams of soil were weighed into each pot and the fertility treatments added.

Laboratory Analyses of Soil Samples

A sufficient amount of each soil was brought to the laboratory for chemical analysis. The samples were air-dried and processed for analysis by crushing the aggregates with a steel roller, and seiving the sample through a twenty mesh sieve.

Soil texture determinations were made by the Pipette method of mechanical analysis (26). Soil reaction was determined with a Beckman, glass electrode pH meter. Fifty grams of soil were mixed with enough water to form a paste. Readings were made after sufficient time had elapsed for the soil solution and the soil to reach equilibrium. Organic matter content of the soil samples was measured indirectly by the "wet combustion process" of organic carbon oxidation (23). Total nitrogen content of the soil was determined by the Kjeldahl method of analysis (23). The cation exchange capacity was determined by a method reported by Russell (47). The exchangeable bases were determined from ammonium acetate leachate by the Beckman Flame Spectrophotometer with photomutiplier attachment on an oxygen-hydrogen flame.

TABLE I

PHYSICAL AND CHEMICAL SOIL CHARACTERISTICS DETERMINED BY LABORATORY ANALYSIS

	"A"	"B"	"C"	"D"	"E"	"F"
Mechanical Composition Pipette Analysis	30.97% Sand 45.59% Silt 19.44% Clay	89.01% Sand 6.55% Silt 4.44% Clay	7.50% Sand 77.30% Silt 15.20% Clay	64.28% Sand 30.12% Silt 5.60% Clay	33.90% Sand 47.34% Silt 18.76% Clay	74.57% Sand 23.07% Silt 2.36% Clay
Soil Reaction	pH 5.2	pH 6.2	pH 5.1	pH 5.7	pH 5.4	pH 6.2
Percent Organic Matter	1.55%	.70%	1.78%	.80%	.95%	.63%
Percent Total Nitrogen	.10%	.04%	.11%	.05%	.06%	.04%
Cation Exchange Capacity m.e./100 gms.	9.80	2.38	7.94	2.88	15.17	1.42
Exchangeable Bases* m.e./100 gms.	6.399	2.622	4.420	2.392	10.650	1.622
Exchangeable Calcium m.e./100 gms.	3.458	1.400	2.350	1.350	6.410	1.050
Exchangeable Magnesium m.e./100 gms.	2.300	.770	1.500	.610	2.140	.138
Exchangeable Potassium m.e./100 gms.	.308	.130	.179	.214	.205	.130
Exchangeable Sodium m.e./100 gms.	.333	.362	.391	.218	1.895	.304
Total Phosphorus lbs./Ac.	460.00	220.00	600.00	360.00	280.00	272.00
0.1 N Acetic Acid Soluble Phosphorus lbs./Ac.	9.0	7.0	11.0	7.0	7.0	14.0

*The exchangeable bases herein reported are those bases which were leached by the action of neutral normal ammonium acetate pH 7.0.

Total phosphorus and acid-soluble phosphorus were determined colorimeterically. A standard curve was used to convert the machine readings to pounds per acre.

Greenhouse Procedure

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

Fertility treatments were added to the pots on November 16, 1956. On November 21, 1956, inoculated alfalfa seed, Buffalo variety, were planted approximately one-half inch below the soil surface. As the soils were heavily infested with "Damping Off Organisms", subsequent plantings had to be made in order to obtain ten healthy plants per pot. Twenty pounds of nitrogen per acre as ammonium nitrate was applied to all pots as a starter fertilizer. On February 10, 1957, ten pounds of borax per acre was added to the Bowie series as the plants in this series were showing boron deficiency symptoms. No magnesium was added as all the soils were well supplied with this nutrient at eight percent or more of the cation exchange capacity. Potassium was added to the soils in an amount calculated to be three percent of the cation exchange capacity. "Soil C" and "Soil E" were not naturally supplied at this level of potassium saturation, therefore, potassium had to be added to these soils.

The plants were thinned to a uniform stand of ten healthy plants per pot. The pots were arranged on greenhouse benches in a completely randomized split plot design.

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

The first harvest was made on April 6, 1957, when the plants were in approximately one-tenth bloom. The second harvest was made on May 24, 1957; the third harvest was made on July 1, 1957. The plants were clipped approximately one-half inch above the soil surface. The plants were taken immediately to the laboratory and autoclaved to stop metabolic activity. The plants were then dried at sixty-five degrees centigrade in a forced-air drying oven for 48 hours. After drying the plants were weighed and the yield recorded. (Refer to Appendix) The dried plant material was ground in a micro Wiley mill until it would pass through a 40 mesh screen, and then stored in small coin envelopes for chemical analysis.

All yield and composition data were submitted to statistical analysis of variance according to the methods of Snedecor (50), and Duncan's range test (14) was also used to evaluate these data. The comparisons of sources of variation in plant yields and composition are given in Tables IX, X, XI, XVIII, XIX, XX, XXVII, XXVIII, XXIX, XXXVI, XXXVII, XXXVIII, XLV, XLVI, XLVII, LIV, LV, LVI.

Soil Treatment

Analytical 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 fifty percent of the total exchange capacity. Each soil required a different rate of calcium carbonate fertilization as shown by the calcium carbonate titration curves. (Refer to Appendix)

Rock phosphate was added to the soils at two rates 750 pounds per acre and 1500 pounds per acre. One-half of the P_2O_5 in the rock phosphate was assumed to be available to alfalfa. Florida land pebble rock phosphate was used in this experiment. Eighty-five percent of this thirty-three percent total P_2O_5 rock phosphate would pass through a 200 mesh screen, and at 105 degrees centigrade this material contained .74 percent moisture.

Calcium monobasic phosphate, $Ca(H_2PO_4) \cdot H_2O$, was used as the superphosphate treatment. Mono calcium phosphate is the major carrier of phosphorus in superphosphate, therefore, the pure chemical was used in this experiment. This material was added in amounts equivalent to the mono calcium phosphate that might be expected in 625 pounds per acre application of twenty percent superphosphate. All the P_2O_5 in this material was considered to be available for plant growth. Under the assumptions of this experiment the 750 pounds per acre rock phosphate treatment was equivalent to 625 pounds per acre superphosphate treatment.

The rock phosphate-superphosphate mixture contained 100 pounds per acre superphosphate and 689.4 pounds per acre rock phosphate. The P_2O_5 in this treatment was equivalent to the total P_2O_5 in the 750 pounds per acre rock phosphate treatment. Combinations and rates of fertilization applications are given in Table II.

Chemical Analyses of Plant Material

A colorimetric procedure as outlined by Harper (23) was used to determine phosphorus in the plant material.

Calcium, magnesium, and potassium were determined by running a small amount of sample from the first phosphorus dilution through a Beckman Model DU Flame Spectrophotometer with a photomultiplier attachment. The fuel gases for this instrument were oxygen and hydrogen. Calcium was measured on a photomultiplier blue sensitive phototube at the electronic resonance line of 424 millimicrons. Magnesium was measured on a magnesium oxide band at 371 millimicrons. Potassium was

TABLE II

GREENHOUSE FERTILIZER TREATMENTS

Treatment Number	Treatment	Rate Per Acre
1	Calcium Carbonate	Soil "A" 1752.00 lbs. Soil "B" 237.89 lbs. Soil "C" 3600.00 lbs. Soil "D" 854.00 lbs. Soil "E" 289.95 lbs. Soil "F" 80.00 lbs.
2	Rock Phosphate	750.00 lbs.
3	Rock Phosphate Calcium Carbonate	750.00 lbs. (Specific as to soil shown in Treat. #1)
4	Superphosphate[1]	625.00 lbs.
5	Superphosphate Calcium Carbonate	625.00 lbs. (Specific as to soil shown in Treat. #1)
6	Rock Phosphate	1500.00 lbs.
7	Rock Phosphate Calcium Carbonate	1500.00 lbs. (Specific as to soil shown in Treat. #1)
8	Rock Phosphate Superphosphate[1]	689.40 lbs. 100.00 lbs.
9	Rock Phosphate Superphosphate[1] Calcium Carbonate	689.40 lbs. 100.00 lbs. (Specific as to soil shown in Treat. #1)

[1]Calcium monobasic phosphate was used as the source of readily available phosphorus in this experiment.

determined on a red sensitive phototube at the electronic resonance line of 774.9 millimicrons. A standard curve was used to transform the machine readings to micrograms of element per milliliter.

Total nitrogen was determined by the Kjeldahl method as outlined by Harper (23).

All yield and plant composition data are reported in grams yield per pot.

IV RESULTS AND DISCUSSION

The Yield of Alfalfa Forage

The Effect of Treatment on Yield

There was a significant treatment difference for three harvests of alfalfa forage as indicated by the F test in Tables IX, X, and XI. These significant differences are shown by a multiple range test at the five percent probability level in Tables XII, XIV, and XVI. There was no significant difference between treatment 7 (rock phosphate 1500 lbs. and calcium carbonate) and treatment 5 (superphosphate and calcium carbonate) for the three alfalfa harvests. Treatments 5 and 7 produced the greatest amount of forage for the three alfalfa harvests, Table III. Treatment 1 produced the least amount of forage, and it was significantly different from all other treatments for the first cutting, Table XII and III. Treatments 2, 3, 4, 6, 8, and 9 were not significantly different at the five percent level with the first harvest. However, they were significantly different from treatments 1, 5, and 7. Treatment 3 was not significantly different from treatment 5 and 7 for the second harvest, Table XIV. There is no significant difference between treatments 1, 2, 4 and 6 for the second and third cuttings; therefore, the assumption was valid that treatment 2 (rock phosphate 750 lbs.) and treatment 4 (superphosphate 625 lbs.) were equivalent as to alfalfa forage yield. For the second and third harvests treatment 8 (rock phosphate-superphosphate) produced the least amount of alfalfa forage, but treatment 9 (rock phosphate-superphosphate plus lime) in contrast to treatment 8 was one of the higher forage producing treatments, as shown in Tables III, XIV, and XVI. The lime and phosphorus treatments grouped together at the upper end of the multiple range test indicated that both lime and phosphorus are limiting on these soils. Calcium carbonate when used in conjunction with rock phosphate did not decrease the availability of the rock phosphate. At the five percent probability level there is no significant difference between treatment 2 and 6 for the three forage harvests; however, treatment 6 was arrayed higher than treatment 2 and produced a greater amount of forage. On the second and third harvests treatment 3 (rock phosphate 750 lbs. and lime) produced more forage than treatment 6, (rock phosphate 1500 lbs.) which indicated the importance of liming for forage production on these soils. The addition of calcium carbonate to the superphosphate treatment greatly increased forage production for three harvests, as shown in Table III. A treatment-soils interaction occurred for the second and third harvests.

There was a significant difference between treatments as to alfalfa forage yield. Although this was a phosphorus experiment the results indicated that both calcium and phosphorus are equally important nutrient elements affecting the yield and composition of alfalfa. When calcium carbonate was added to any phosphorus treatment, an increase in alfalfa forage yield occurred. Treatment 6 (rock phosphate 1500 lbs.) and treatment 4 (superphosphate 625 lbs.) were equivalent as to alfalfa forage production. Rock phosphate 1500 lbs. and superphosphate 625 lbs. were significantly different from treatments 5 and 7, thus showing the effect of calcium carbonate upon alfalfa forage yield. These results are in agreement with Phibbs (41) who reported no significant difference between alfalfa hay yields from superphosphate-lime and rock phosphate-lime treatments. Other investigators (32, 21) have reported an increase in forage yields when calcium carbonate was applied with rock phosphate as in treatments 3, 7, and 9.

Treatment 2 (rock phosphate 750 lbs.) was not significantly different from treatment 4 (superphosphate 625 lbs.), therefore, the assumption that one-half of the P_2O_5 in rock phosphate was equivalent to the total P_2O_5 in superphosphate at 625 pounds per acre is valid. Nickols (38) reported similar results. Pots which received treatment 6 (rock phosphate 1500 lbs.) produced more forage than pots receiving treatments 2 and 4; therefore, twice the amount of P_2O_5 from rock phosphate was required to stimulate the same yield as the superphosphate, treatment 4 (42, 44).

A decrease in forage occurred when rock phosphate and superphosphate, treatment 8, were applied together without lime. Treatment 9 (rock phosphate-superphosphate and lime) gave an increase in alfalfa yield. Treatment 9 produced more alfalfa forage than did treatments 2 and 4 (rock phosphate 750 lbs. and superphosphate 625 lbs. respectively). Jones (28) reported the same relationship as to rock phosphate and superphosphate mixtures.

The Effect of Soils on Yield

A significant difference as to soils was found for three alfalfa harvests, Tables XIII, XV, and XVII. For three harvests Soil "A" was significantly different from all other soils, and more alfalfa forage was produced on this soil. Soil "D" ranked second to Soil "A" for the three harvests. Soil "F" produced the least amount of forage, and it was significantly different from Soils "A" and "D" on the first cutting;

it was significantly different from Soil "A" only the second cutting; for the third cutting it was significantly different from Soils "E", "C", "D", and "A". Although Soil "E" had the highest exchange capacity, it produced less alfalfa than Soils "D", "C", "B", or "A", Table III. Phosphorus, calcium, magnesium, and potassium were added to these soils in amounts sufficient to meet the growth requirements of alfalfa. The result of this experiment indicates that factors either chemical or physical are active in these soils, and these factors materially affected the growth of alfalfa. Soils "B" and "F" were not significantly different through three cuttings, Tables XIII, XV, and XVII. No relationship could be determined statistically at the five percent probability level as to geographical regions, but on the basis of total yield from each region a relationship probably exists. The three geographical regions ranked in descending order as to yield were as follows: Central, > Northeast, > and Southeast, and more alfalfa forage was produced on the prairie soils than on the timbered soils, Table III.

Through the three harvests Soil "A" was more responsive to the fertility treatments than the other soils. Pots containing Soil "A" produced the greatest amount of alfalfa forage. The physical and chemical characteristics of this soil were very favorable for the growth of alfalfa. Soil "E" although a very excellent soil chemically was one of the lower alfalfa producing soils. This soil had the highest amount of exchangeable sodium; this amount of sodium (12% of exchange capacity) is nearing the level generally thought of as causing deflocculation. The physical condition of this soil in the greenhouse pots was extremely poor. The soil deflocculated which caused poor aeration and water infiltration.

TABLE XII. A MULTIPLE RANGE TEST SHOWING DIFFERENCES OF FIRST ALFALFA HARVEST YIELD DUE TO THE EFFECTS OF TREATMENTS

A. Standard Error of Mean: $\sqrt{\dfrac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .468$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
R_p:	1.32	1.39	1.43	1.47	1.49	1.51	1.53	1.55	

C. Results:

T_1	T_8	T_2	T_3	T_9	T_6	T_4	T_7	T_5
6.52	8.33	8.34	9.03	9.20	9.39	9.42	10.88	11.17

TABLE XIII. A MULTIPLE RANGE TEST SHOWING DIFFERENCES BETWEEN SOIL FOR FIRST ALFALFA HARVEST YIELD DUE TO THE EFFECTS OF TREATMENTS

A. Standard Error of Mean: $\sqrt{\dfrac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .486$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	1.50	1.57	1.62	1.63	1.65

C. Results:

"F"	"E"	"C"	"B"	"D"	"A"
7.60	7.82	8.88	9.18	9.32	12.04

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE XIV. A MULTIPLE RANGE TEST SHOWING DIFFERENCES OF SECOND ALFALFA HARVEST YIELD DUE TO THE EFFECTS OF TREATMENTS

A. Standard Error of Mean: $\sqrt{\dfrac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .286$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	.80	.84	.87	.89	.91	.92	.93	.94

C. Results:

T_8	T_4	T_1	T_2	T_6	T_9	T_3	T_7	T_5
4.93	5.49	5.53	5.57	6.33	6.72	7.15	7.69	7.76

TABLE XV. A MULTIPLE RANGE TEST SHOWING DIFFERENCES BETWEEN SOILS FOR SECOND ALFALFA HARVEST YIELD DUE TO THE EFFECTS OF TREATMENTS

A. Standard Error of Mean: $\sqrt{\dfrac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .345$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	1.06	1.11	1.15	1.16	1.17

C. Results:

"B"	"F"	"E"	"C"	"D"	"A"
5.42	5.68	5.74	5.95	6.55	8.66

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE XVI. A MULTIPLE RANGE TEST SHOWING DIFFERENCES OF THIRD ALFALFA HARVEST YIELD DUE TO THE EFFECTS OF TREATMENTS

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .215$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	.60	.63	.66	.67	.68	.69	.70	.71

C. Results:

T_8	T_2	T_1	T_4	T_6	T_3	T_9	T_5	T_7
4.11	4.47	4.73	4.75	4.78	5.81	5.81	6.10	6.18

TABLE XVII. A MULTIPLE RANGE TEST SHOWING DIFFERENCES BETWEEN SOILS FOR THIRD ALFALFA HARVEST YIELD DUE TO THE EFFECTS OF TREATMENTS

A. Standard Error of Mean: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .207$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.64	.67	.69	.70	.73

C. Results:

"F"	"B"	"E"	"C"	"D"	"A"
4.16	4.47	4.84	5.14	5.39	7.15

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

Soil "D" ranked second in alfalfa forage production. This soil had a higher exchange capacity than the other wooded soils, but it had a lower exchange capacity than either of the prairie soils. Why Soil "D" produced more forage than Soils "B", "C", "E", and "F" is not known, however, this soil may contain a very active clay. Soils "B" and "F" were not significantly different as to alfalfa forage yields. The natural fertility status of these soils was lower than for the other soils; therefore, these soils produced the least amount of alfalfa forage. Soil "C" ranked third as to alfalfa forage yield. Soil "C" had the highest amount of soluble and available phosphorus, and this might explain its slow response to phosphorus fertilization. This soil had poor physical characteristics.

Calcium, potassium, and magnesium were added to these soils in amounts sufficient to meet the growth requirements of alfalfa. No relationship as to soil type or geographical regions could be determined statistically as to forage yield.

The Effect of Treatment on Phosphorus Composition

The analysis of variance F test for three alfalfa harvests shows a significant difference as to phosphorus composition as affected by treatment, Tables XVIII, XIX, and XX. For three alfalfa harvests treatment 5 (superphosphate-calcium carbonate) was significantly different from all other treatments as determined by the multiple range tests, Tables XXI, XXIII, and XXV. Treatment 1 (calcium carbonate) was significantly lower than all other treatments for three alfalfa cuttings. Treatments 2 and 3 were not significantly different at the five percent probability level, however, treatment 3 consistently ranked above treatment 2 in the multiple range test. Treatment 4 (superphosphate) was significantly higher than treatment 2 (rock phosphate 750 lbs.) for the first and second harvests and ranked above treatment 2 for the third harvest. Plants grown on the superphosphate 625 pounds per acre treatment contained more phosphorus than plants grown on the rock phosphate 750 pounds per acre, Table IV. Calcium carbonate in combination with all phosphorus treatments increased the availability of the phosphorus in this experiment. From this data it is evident that there is no depressive interaction on phosphorus uptake between rock phosphate and calcium carbonate as reported by Nichols (38). Treatments 4 and 6 were not significantly different through three alfalfa harvests indicating that superphosphate 625 pounds per acre and rock phosphate 1500 pounds per acre will yield an equivalent amount of phosphorus to alfalfa, Tables XXI, XXIII, and XXV. There was no significant increase in yield over treatment 2 (rock phosphate 750 lbs.) by mixing rock phosphate and superphosphate as in treatment 8. Treatments 1, 2, 8, and 9 were consistently bunched at the lower end of the multiple range test for the three harvests. Treatments 5 and 7 were significantly different, but treatment 7 ranked second to treatment 5 in the multiple range test.

The greatest amount of phosphorus uptake occurred on pots which had received treatment 5 (superphosphate 625 lbs. and lime). This result was in agreement with McLean (35). Treatment 7 (rock phosphate 1500 lbs. and lime) although significantly different from treatment 5 was ranked second to treatment 5 in total grams of phosphorus uptake. Phosphorus uptake by alfalfa was higher from the superphosphate 625 pounds treatment 4, than either treatment 3 or 4. Therefore, phosphorus availability from treatments 2 and 4 are not equivalent (38). Treatment 4 (superphosphate 625 lbs.) and treatment 6 (rock phosphate 1500 lbs.) are not significantly different; therefore, under the conditions of this experiment it took four times as much total P_2O_5 from rock phosphate as superphosphate for an equivalent amount of phosphorus uptake by alfalfa (42, 44).

There was a significant increase in phosphorus uptake by alfalfa due to calcium carbonate. Addition of calcium carbonate to the phosphorus treatments greatly increased the availability of both rock phosphate and superphosphate phosphorus (32, 41). Treatments 8 and 9 were two of the lowest treatments as to phosphorus availability. No benefit was gained as to phosphorus uptake by mixing rock phosphate and superphosphate.

The Effect of Soils on Phosphorus Composition

There was a significant difference between soils as to phosphorus uptake, Tables XVIII, XIX, and XX. There was a greater amount of phosphorus from Soil "A" than from the other soils, Table IV. There was no significant difference between Soils "A" and "D" the first two harvests, however, on the third harvest Soil "A" was significantly different from Soil "D". Soil "E" was ranked lowest for all three alfalfa harvests, and it was significantly different from all soils the first and third harvests, Tables XXII and XXVI. There was no significant difference between Soils "B", "C", and "E" the second harvest, Table XXIV. There was no significant difference between Soils "C" and "F" for the three alfalfa harvests. These two soils were not significantly different from Soil "B" for the second and third harvests, Tables XXII, XXIV, and XXVI. There was a great increase in the phosphorus uptake from Soil "F"

TABLE XXI. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF FIRST ALFALFA HARVEST PHOSPHORUS UPTAKE DUE TO THE EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .129$

B. Shortest Significant Ranges:									
p: (5% p-level)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:		.361	.381	.393	.402	.410	.415	.421	.424
C. Results:	T_1	T_2	T_3	T_8	T_9	T_6	T_4	T_7	T_5
	1.08	1.79	1.85	1.89	1.89	2.21	2.37	2.39	2.92

TABLE XXII. A MULTIPLE RANGE TEST SHOWING PHOSPHORUS DIFFERENCES BETWEEN SOILS FOR FIRST ALFALFA HARVEST DUE TO THE EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .075$

B. Shortest Significant Ranges:						
p: (5% p-level)		(2)	(3)	(4)	(5)	(6)
R_p:		.231	.242	.250	.252	.255
C. Results	"E"	"F"	"C"	"B"	"A"	"D"
	1.57	1.87	2.07	2.14	2.29	2.33

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE XXIII. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF SECOND ALFALFA HARVEST PHOSPHORUS UPTAKE DUE TO THE EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}}$ = .064

B. Shortest Significant Range:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	.179	.189	.195	.200	.204	.206	.209	.211

C. Results:

T_1	T_8	T_2	T_9	T_3	T_6	T_4	T_7	T_5
.778	1.200	1.278	1.283	1.383	1.489	1.494	1.561	1.956

TABLE XXIV. A MULTIPLE RANGE TEST SHOWING PHOSPHORUS DIFFERENCES BETWEEN SOILS FOR SECOND ALFALFA HARVEST DUE TO THE EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}}$ = .094

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.290	.304	.313	.316	.320

C. Results:

"E"	"C"	"B"	"D"	"F"	"A"
1.004	1.185	1.337	1.474	1.485	1.756

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE XXV. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF THIRD ALFALFA HARVEST PHOSPHORUS UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .056$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
R_p:	.157	.165	.171	.175	.178	.180	.183	.184	

C. Results:

T_1	T_8	T_2	T_9	T_6	T_4	T_3	T_7	T_5
.850	1.139	1.200	1.322	1.328	1.339	1.344	1.533	1.739
		———	———	———	———	———	———	———
———	———	———						

TABLE XXVI. A MULTIPLE RANGE TEST SHOWING PHOSPHORUS DIFFERENCES BETWEEN SOILS FOR THIRD ALFALFA HARVEST DUE TO THE EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .056$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.172	.181	.186	.188	.190

C. Results:

"E"	"C"	"F"	"B"	"D"	"A"
.978	1.204	1.226	1.267	1.456	1.733
				———	———
———	———	———	———		

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

for the second harvest over the first harvest; however, Soil "F" was ranked at the lower end of the multiple range test the first and third harvests, Tables XXII, XXIV, and XXVI. No explanation for this sudden increase in phosphorus uptake on the second harvest can be given. No statistical relationship was found as to geographical regions, but on the basis of total phosphorus uptake the regions were ranked in order as follows: Central, $>$ Northeast, $>$ and Southeast, Table IV. This ranking coincides with the total forage yield ranking for the geographical regions. There was a treatment-soil interaction for phosphorus uptake for all three alfalfa harvests, Tables XVIII, XIX, and XX. Phosphorus uptake was greater on the timber soils than on the prairie soils.

Phosphorus uptake was greatest from Soils "A" and "D". These soils were high in natural phosphorus as compared to the other soils with the exception of Soil "C". Soil "C" had the greatest amount of both available and total phosphorus yet it ranked fifth as to the amount of phosphorus taken up. Some factor or factors unknown to the author caused this decrease. Soil "E" was ranked last as to phosphorus uptake; therefore, the low forage yield on this soil may be due to phosphorus deficiencies. This soil was naturally low in total phosphorus, and Soils "B" and "F", both wooded soils, were grouped together at the lower end of the multiple range test. These soils were low in total phosphorus and other nutrient elements.

The Effect of Treatment on Calcium Composition

Analysis of variance Tables XXVII, XXVIII, and XXIX show a significant difference between treatment as to calcium composition of alfalfa. These significant differences at a five percent probability level are shown by means of a multiple range test. Treatments 5, 7, and 9 were not significantly different for this first harvest. Treatments 3, 5, 7, and 9 were not significantly different for the second and third harvests, Tables XXX, XXXII, and XXXIV. Phosphorus and calcium carbonate treatments grouped together at the top of the multiple range test indicate that calcium carbonate increased the amount of calcium uptake by alfalfa. Calcium uptake was greatest from pots receiving treatment 7 (rock phosphate 1500 lbs. and calcium carbonate) and treatment 5 (superphosphate and calcium carbonate) was second, Table V. There is a calcium-phosphorous relationship because the calcium uptake by alfalfa from treatment 1 (calcium carbonate) was not as high for this treatment as for treatments 3, 5, 7, and 9, which were phosphorus treatments plus lime. In order for the alfalfa plant to be adequately supplied with calcium it must also be supplied with phosphorus. Treatment 1 was ranked lowest for the first harvest; however, the uptake of calcium from this treatment increased with each harvest, and on the third harvest treatment 1 was ranked above and significantly different from treatments 2, 4, 6, and 8. There was not enough calcium in rock phosphate, superphosphate, or rock phosphate-superphosphate to adequately meet the calcium requirement. Treatment 8 (rock phosphate-superphosphate) ranked last for the second and third harvests of alfalfa whereas treatment 9 (rock phosphate-superphosphate and calcium carbonate) was ranked at the upper end of the multiple range test and it was significantly higher, Tables XXXII and XXXIV. Calcium uptake was greater from treatment 6 than from treatments 2 and 4, Table V. Double the amount of rock phosphate, treatment 6, slightly increased the amount of available calcium to alfalfa. There was a significant soil-treatment interaction for the second and third harvests.

The calcium-phosphorus treatments were grouped together at the end of the multiple range test indicating that calcium-phosphorus interactions increases the uptake of phosphorus from these soils (32, 38, 42). Calcium uptake was greatest from pots receiving treatment 7 (rock phosphate 1500 lbs. and lime) followed by treatment 5 (superphosphate 625 lbs. and lime). More calcium was supplied to the plant from 1500 pounds rock phosphate than from 750 pounds rock phosphate or 625 pounds superphosphate. Treatment 1 (calcium carbonate) did not yield so much calcium to alfalfa as did treatments 3, 5, 7, and 9, which indicates that a calcium-phosphorus interaction increased the availability of calcium. Bear (4) states that a cation-anion ratio must be maintained in order for maximum crop production.

The Effect of Soils on Calcium Composition

There was a significant difference between soils for three harvests alfalfa, Tables XXVII, XXVIII, and XXIX. Calcium uptake was less from Soils "F" and "B" than from the other soils, Table V. Soil "C" was not significantly different from Soil "F" on the first cutting, but it consistently increased in calcium uptake, and on the third harvest it was second to Soil "A", Tables XXXI, XXXIII, and XXXV. Soil "E" was not significantly different from Soil "A" for the first two harvests, but for the third harvest it was significantly different from Soils "A" and "C". There was no significant difference between Soils "D" and "E" for the three harvests. For the third harvest the prairie soils were aligned at the top of the multiple range, while the timber soils were grouped together at the lower end of the multiple range test. The prairie soils had higher cation exchange capacities than the timber soils;

TABLE XXX. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF FIRST ALFALFA HARVEST CALCIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .898$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	2.514	2.649	2.739	2.802	2.856	2.892	2.927	2.954

C. Results:

T_1	T_2	T_8	T_6	T_4	T_3	T_9	T_5	T_7
9.772	11.406	11.444	12.606	12.622	16.039	16.628	17.772	19.044

TABLE XXXI. A MULTIPLE RANGE TEST SHOWING CALCIUM DIFFERENCES BETWEEN SOILS FOR FIRST ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .735$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	2.264	2 374	2.448	2.470	2.499

C. Results:

"F"	"C"	"B"	"D"	"E"	"A"
10.937	13.113	14.193	15.037	15.522	17.074

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE XXXII. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF SECOND ALFALFA HARVEST CALCIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .358$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
R_p:	1.002	1.056	1.092	1.117	1.138	1.153	1.167	1.178	

C. Results:

T_8	T_4	T_2	T_1	T_6	T_9	T_3	T_5	T_7
4.883	4.967	5.689	6.183	6.311	8.678	8.878	9.506	9.744

TABLE XXXIII. A MULTIPLE RANGE TEST SHOWING CALCIUM DIFFERENCES BETWEEN SOILS FOR SECOND ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .461$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	1.420	1.489	1.535	1.549	1.567

C. Results:

"F"	"B"	"C"	"D"	"E"	"A"
5.878	6.233	6.889	7.200	7.811	9.215

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE XXXIV. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF THIRD ALFALFA HARVEST CALCIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .317$

B. Shortest Significant Ranges:

p:	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
R_p:	.888	.935	.967	.989	1.008	1.021	1.033	1.043	

C. Results:

T_8	T_2	T_6	T_4	T_1	T_9	T_3	T_5	T_7
3.744	3.989	4.356	4.428	5.439	6.644	6.728	6.744	7.233

TABLE XXXV. A MULTIPLE RANGE TEST SHOWING CALCIUM DIFFERENCES BETWEEN SOILS FOR THIRD ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .361$

B. Shortest Significant Ranges

p:	(2)	(3)	(4)	(5)	(6)
R_p:	1.112	1.166	1.202	1.213	1.227

C. Results:

"F"	"B"	"D"	"E"	"C"	"A"
4.093	4.548	5.333	5.363	6.511	7.022

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

therefore, the prairie soils contained more calcium which was available to alfalfa, Tables XXXV and V. The geographical regions ranked in descending order as to total calcium yield were as follows: Central, >Northeast,> and Southeast.

Soils "F" and "B" contained the least amount of exchangeable calcium. These two soils were ranked together at the lower end of the multiple range test. These soils have a small amount of clay; therefore, their chemical capabilities are small, and this would seem to be the reason for the lower amount of calcium taken up from these soils in comparison to the other soils. Soil "E" which had the greatest amount of natural calcium was second to Soil "A" as to total calcium uptake by alfalfa. Soil "C" continually increased in calcium uptake for three harvests. There was no statistical relationship as to soil type.

The Effect of Treatment on Magnesium Composition

The effect of treatments on magnesium composition of alfalfa was significantly different as shown in the analysis of variance, Tables XXXVI, XXXVII, and XXXVIII. There was no significant difference in magnesium uptake between treatments 3, 5, 7, and 9 for the three alfalfa harvests. These treatments were grouped at the top of the multiple range test, Tables XXXIX, XLI, and XLIII. Treatments 1, 2, 4, 6, and 8 were not significantly different at the five percent level, and they were grouped at the lower end of the multiple range test, third harvest, Table XLIII. These data indicate that a direct relationship exists between magnesium uptake and soil calcium. Treatment 1 (calcium carbonate) was significantly different from all treatments for the first harvest, Table XXXIX; however, the magnesium uptake from pots with this treatment increased thereafter with each harvest. At the five percent probability level treatments 2 and 6 were not significantly different for the three harvests, but treatment 6 consistently ranked above treatment 2, that is more magnesium was taken up from pots receiving treatment 6, Table VI. Magnesium uptake from pots receiving treatment 5 decreased with harvests, whereas, pots that received treatment 7 increased in magnesium uptake. Treatments 2 and 8 were ranked at the lower end of the multiple range test, whereas, the same phosphorus treatments 3 and 9 with the addition of lime were ranked at the top of the multiple range tests, Tables XXXIX, XLI, XLIII, and VI.

Treatment groupings in the multiple range test were very similar to those for calcium. The calcium and phosphorus treatments were ranked at the top of the multiple range test, whereas, the phosphorus treatments alone ranked at the bottom of the multiple range test. Therefore, there was a calcium-magnesium-phosphorus relationship (4). Treatments 3 and 7 were not statistically different, but both treatments were statistically different from treatment 2; therefore, the magnesium uptake from treatment 3 was equivalent to treatment 7. Rock phosphate-superphosphate mixture without lime showed a decreased uptake of magnesium over rock phosphate-superphosphate and lime which was one of the highest ranked treatments.

The Effect of Soils on Magnesium Composition

There was a significant difference between soils as to magnesium uptake as indicated by analysis of variance, Tables XXXVI, XXXVII, and XXXVIII. For the first harvest Soil "F" was significantly different from all other soils. There was less magnesium uptake from this soil than from the other soils, Table VI. Soil "A" was significantly

TABLE XXXIX. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF FIRST ALFALFA HARVEST MAGNESIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .291$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	.815	.858	.888	.908	.925	.937	.949	.957

C. Results:

T_1	T_2	T_8	T_3	T_6	T_9	T_4	T_7	T_5
3.411	4.667	4.744	5.061	5.272	5.294	5.394	5.828	5.933

TABLE XL. A MULTIPLE RANGE TEST SHOWING MAGNESIUM DIFFERENCES BETWEEN SOILS FOR FIRST ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .158$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.487	.510	.526	.531	.537

C. Results:

"F"	"E"	"D"	"B"	"A"	"C"
3.352	4.393	5.056	5.233	6.070	6.300

Note: Any two means not underscored by the same line are significantly different. Any two means under-lined by the same line are not significantly different.

TABLE XLI. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF SECOND ALFALFA HARVEST MAGNESIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}}$ = .136

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	.381	.401	.415	.424	.432	.438	.443	.447

C. Results:

T_8	T_4	T_1	T_2	T_6	T_9	T_3	T_7	T_5
2.361	2.494	2.539	2.650	3.039	3.267	3.450	3.556	3.600
					———	———	———	———
				———	———	———		
			———	———				
———	———	———	———					

TABLE XLII. A MULTIPLE RANGE TEST SHOWING MAGNESIUM DIFFERENCES BETWEEN SOILS FOR SECOND ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}}$ = .156

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.480	.504	.519	.524	.530

C. Results:

"E"	"F"	"B"	"D"	"C"	"A"
2.207	2.344	2.707	3.026	3.470	4.215
					———
			———	———	
		———	———		
———	———	———			

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE XLIII. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF THIRD ALFALFA HARVEST MAGNESIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}$ = .113

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
R_p:	.316	.333	.345	.353	.359	.364	.368	.372	
C. Results:	T_2	T_8	T_4	T_6	T_1	T_5	T_3	T_9	T_7
	2.039	2.061	2.167	2.228	2.294	2.722	2.783	2.811	2.900

TABLE XLIV. A MULTIPLE RANGE TEST SHOWING MAGNESIUM DIFFERENCES BETWEEN SOILS FOR THIRD ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10^2

A. Standard Error of Means: $\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}$ = .117

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	
R_p:	.360	.378	.390	.393	.398	
C. Results:	"F"	"E"	"B"	"D"	"C"	"A"
	1.674	2.004	2.430	2.507	3.026	2.030

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

different from Soil "C" for the second harvest only; however, in total magnesium uptake it was the greater of the two soils, Tables XL, XLII, XLIV, and VI. There was a grouping of soils in the multiple range tests. The groups as they were arrayed in the multiple range test were as follows: "A" and "C", "D" and "B", "E" and "F". Magnesium uptake from Soil "E" was limited although it was supplied with sufficient magnesium for alfalfa. Some unknown factor limits the availability of magnesium in this soil. The geographical regions ranked in descending order as to total magnesium uptake were as follows: Central, > Northeast, > and Southeast, Table VI. Magnesium uptake was greater from the prairie soils than from the wooded soils.

The soils varied as to magnesium uptake. There was less magnesium uptake from Soil "F" than from the other soils. This soil had the least amount of natural magnesium present. There was a relationship within geographical regions as more grams of magnesium were taken up from the prairie soils than the timber soils. Calcium uptake from Soil "E" was high whereas the magnesium and phosphorus uptake was low. Soils "A" and "C" were high in magnesium; therefore, the alfalfa on these soils was higher in magnesium.

The Effect of Treatment on Potassium Composition

A significant difference between treatments as to potassium uptake is shown in analysis of variance, Tables XLV, XLVI, and XLVII. Treatment 1 (calcium carbonate) was significantly different from treatments 5, 6, and 7. There was no significant difference between the other treatments at the five percent probability level, Table XLVII. Potassium uptake from pots containing treatment 1 increased for the second and third harvests, and treatment 1 was not significantly different from treatments 3, 5, 7, and 9 for the third harvest, Tables XLVIII, L, LII. There was no significant difference in potassium uptake between treatments 3, 5, 7, and 9 for the three alfalfa harvests; however, there was more potassium uptake from pots containing treatment 5, Table VII. Treatment 2 (rock phosphate 750 lbs.) and treatment 4 (superphosphate 625 lbs.) were not significantly different at the five percent level, but treatment 2 ranked above treatment 4 for all three alfalfa harvests. From the first to the third harvest there was a great increase in potassium uptake from treatment 9, whereas, treatment 8 was ranked last in the multiple range test as to potassium uptake. A greater amount of potassium was taken up from treatment 3 than treatment 2 indicating the influence of liming on potassium uptake. Potassium uptake decreased with each harvest on treatment 6 (rock phosphate 1500 lbs.) whereas with treatment 7 (rock phosphate 1500 lbs. and calcium carbonate) there was an increase in potassium uptake. Treatments 3 and 6 were significantly different for the second and third harvests, and more potassium was taken up from treatment 3, Tables VII, L, and LII. There was a higher potassium uptake from the phosphorus and calcium carbonate treatments, Table VII. A significant interaction between soils and treatment occurred for the second and third alfalfa harvests. The geographical regions ranked in descending order as to total potassium uptake were as follows: Central, $>$ Southeast, $>$ and Northeast. An increase in potassium uptake from Soil "E" explains why the Southeast region ranks above the Northeast region.

Potassium uptake was closely related to calcium carbonate treatments. Uptake of potassium from pots containing treatment 1 (calcium carbonate) continually increased for the three harvests. Treatment 1 ranked above treatments 2, 4, 6, and 8 in the multiple range test. Potassium uptake from pots containing treatment 9 (rock phosphate-superphosphate and lime) increased with each harvest, whereas, treatment 8 (rock phosphate-superphosphate) was one of the lower treatments. For this experiment no inverse relationship exists between calcium and potassium as reported by Nickols (38). These data agree with Bear (4) who states that there is a constant relationship between cations and anions in the plants. Potassium uptake from treatment 6 (rock phosphate 1500 lbs.) was ranked above treatment 2 (rock phosphate 750 lbs.) indicating that large amounts or rock phosphate will increase the availability of potassium (38).

The Effect of Soils on Potassium Composition

A significant difference between soils as to potassium uptake is shown in the analysis of variance, Tables XLV, XLVI, and XLVII. Soil "A" was significantly different from the other soils for three alfalfa harvests, Tables XLIX, LI, and LIII. There was no significant difference between the other five soils for the first harvest, Table XLIX. Potassium uptake from Soil "F" increased with the first two harvests, but on the third harvest a sharp decrease in potassium uptake occurred. There was a constant increase in potassium uptake from Soil "E" for the three harvests, Table LIII. Soil "C" and "D" were not significantly different; however, potassium uptake was greater from Soil "D", Table VII. Soils "B", "C", "D", "E", and "F"

TABLE XLVIII. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF FIRST ALFALFA HARVEST POTASSIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .141$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	.395	.416	.430	.440	.448	.454	.460	.464

C. Results:

T_1	T_8	T_4	T_9	T_2	T_3	T_6	T_5	T_7
1.844	2.117	2 192	2.221	2.241	2.281	2.348	2.539	2.567

TABLE XLIX. A MULTIPLE RANGE TEST SHOWING THE POTASSIUM DIFFERENCES BETWEEN SOILS FOR FIRST ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .123$

B. Shortest Significant Ranges

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.379	.397	.410	.413	.418

C. Results:

"C"	"E"	"D"	"F"	"B"	"A"
1.898	1.991	2.162	2.172	2.232	3.113

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE L. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF SECOND ALFALFA HARVEST POTASSIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .078$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	.218	.230	.238	.243	.248	.251	.254	.257

C. Results:

T_8	T_4	T_2	T_1	T_6	T_9	T_3	T_5	T_7
1.251	1.283	1.417	1.482	1.621	1.634	1.727	1.749	1.785

TABLE LI. A MULTIPLE RANGE TEST SHOWING POTASSIUM DIFFERENCES BETWEEN SOILS FOR SECOND ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .067$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.206	.216	.223	.225	.228

C. Results:

"B"	"D"	"C"	"E"	"F"	"A"
1.223	1.386	1.399	1.594	1.802	2.496

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE LII. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF THIRD ALFALFA HARVEST POTASSIUM UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .054$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	.151	.159	.165	.168	.173	.175	.177	.179

C. Results:

T_8	T_4	T_2	T_6	T_1	T_5	T_7	T_3	T_9
1.076	1.093	1.138	1.155	1.254	1.321	1.339	1.351	1.406

TABLE LIII. A MULTIPLE RANGE TEST SHOWING POTASSIUM DIFFERENCES BETWEEN SOILS FOR THIRD ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .056$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.172	.181	.186	.188	.190

C. Results:

"F"	"B"	"C"	"D"	"E"	"A"
.923	1.024	1.095	1.107	1.340	1.934

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

were not significantly different for the third harvest, Table LIII. The inverse relationship noted by Nickols (38) between potassium and calcium uptake did not occur with these soils. The soils which had the highest calcium uptake by alfalfa also had the highest uptake of potassium. Potassium uptake from Soil "A" was much higher than from the other soils, Table VII.

There was a very small difference between Northeast and Southeast regions as to potassium uptake, but the Central region ranked above the other two regions. There was very little difference between soils as to potassium uptake. Potassium was more available from Soil "A" than from the other soils. This soil had the greatest amount of natural potassium. The increase of potassium from Soil "E" could be attributed to the potassium added in order to raise the potassium saturation level to three percent. Potassium in the prairie soils was more available than the potassium in the timbered soils. For this experiment no inverse relationship existed between calcium and potassium as has been previously reported (38). The soils which had the highest amount of calcium also had the highest uptake of potassium.

The Effect of Treatment on Nitrogen Composition

A significant difference between treatments in nitrogen uptake is shown for the analysis of variance tables for nitrogen, Tables LIV, LV, and LVI. The highest uptake of nitrogen occurred on pots which had treatments 5 and 7. These soils were not significantly different for three alfalfa harvests, Tables LVII, LIX, and LXI. Treatment 1 (calcium carbonate) was ranked last for the first alfalfa harvest, but for the third harvest it ranked above treatments 2, 4, 6, and 8 which were phosphorus treatments without lime. Treatments 1, 2, 4, and 8 were not significantly different for the second and third harvests, Tables LIX and LXI. On the third harvest the treatments were aligned into two separate groups as shown by the multiple range test. Treatments 3, 5, 7, and 9 were arrayed at the top of the multiple range test, whereas, treatments 1, 2, 4, and 8 were arrayed at the bottom of the multiple range test, Table LXI. Although treatment 6 was not significantly different from treatments 2 and 4, it was ranked above both treatments for the second and third alfalfa harvests, which indicated that nitrogen uptake was directly related to phosphorus uptake, Tables LIX, LXI, and VIII. Treatment 8 was not significantly different from treatments 2 and 4, but there was less nitrogen uptake from pots with this treatment, Table VIII. Nitrogen uptake was greater from treatment 9 than from treatments 2 and 4, Table VIII. Nitrogen uptake is probably directly related to the calcium and phosphorus status of the soil. Geographical regions ranked in descending order as to total nitrogen uptake were as follows: Central, $>$ Northeast, $>$ and Southeast.

Pots containing phosphorus and calcium treatments continually increased in nitrogen uptake. Nitrogen uptake was greatest from pots containing treatments 5 and 7, and both of these treatments were significantly different from comparable treatments (5 and 6) without lime. Part of this increase in nitrogen uptake might be attributed to an increase in yield. Bear (4) suggests that there is an anion relationship, and plants that are high in phosphorus would also be expected to be high in nitrogen. Nitrogen uptake was higher by plants grown in pots containing superphosphate than pots containing rock phosphate;

however, all lime and phosphorus plus lime treatments gave an increase in nitrogen uptake over calcium carbonate alone.

<u>The Effect of Soils on Nitrogen Uptake</u>

A significant difference between soils as to nitrogen uptake is shown in the analysis of variance tables for nitrogen, Tables LIV, LV, and LVI. A soil-treatment interaction occurred for the second and third harvests. Nitrogen uptake was greatest from Soil "A" for three alfalfa cuttings, Table VIII. Soils "E" and "E" were significantly different from Soils "A", "C", and "D", Table LVIII. For the first harvest soils "B", "C", "D", "E", and "F" were not significantly dif- fierent from the second harvest, Table LX. On the third harvest the soils were aligned in three distinct groups, which were significantly different from each other. Soils "B", "E", and "F" were grouped together at the lower end of the multiple range test, and Soils "C" and "D" were ranked higher, but they were significantly different from Soil "A", Table LXII. Nitrogen uptake from the prairie soils was greater than from the timbered soils, Table VIII.

Conditions favorable for nitrogen fixation was greatest on Soil "A". There was no significant difference in nitrogen uptake between soils except for Soil "A" on the second harvest. On the third harvest the soils were grouped into two distinct groups. Soils "B", "E", and "F" were grouped together at the lower end of the multiple range table. Soils "B" and "F" had poor chemical characteristics which probably account for the lower nitrogen fixation and uptake from these soils. Soil "E" had desirable chemical properties, but its very poor physical characteristics were unfavorable for nitrogen fixation. This soil has

TABLE LVII. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF FIRST ALFALFA HARVEST NITROGEN UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .168$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
R_p:	.470	.496	.512	.524	534	.541	.548	.553	

C. Results:

T_1	T_8	T_2	T_6	T_4	T_3	T_9	T_7	T_5
2.188	2.496	2.643	2.868	2.872	3.003	3.008	3.527	3.707

TABLE LVIII. A MULTIPLE RANGE TEST SHOWING NITROGEN DIFFERENCES BETWEEN SOILS FOR FIRST ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .174$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.536	.562	.579	.585	.592

C. Results:

"E"	"F"	"B"	"C"	"D"	"A"
2.354	2.482	2.899	3.032	3.193	3.581

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE LIX. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF SECOND ALFALFA HARVEST NITROGEN UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}}$ = .081

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
R_p:	.227	.239	.247	.253	.258	.261	.264	.266	

C. Results:

T_8	T_1	T_2	T_4	T_6	T_9	T_3	T_7	T_5
1.438	1.596	1.611	1.613	1.846	1.998	2.155	2.286	2.300

TABLE LX. A MULTIPLE RANGE TEST SHOWING NITROGEN DIFFERENCES BETWEEN SOILS FOR SECOND ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}}$ = .110

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.339	.355	.366	.370	.374

C. Results:

"B"	"F"	"E"	"C"	"D"	"A"
1.584	1.604	1.649	1.874	1.918	2.600

Note: Any two means not underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

TABLE LXI. A MULTIPLE RANGE TEST SHOWING THE DIFFERENCES OF THIRD ALFALFA HARVEST NITROGEN UPTAKE DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .057$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R_p:	.160	.168	.174	.178	.181	.184	.186	.188

C. Results:

T_8	T_2	T_4	T_6	T_1	T_9	T_3	T_5	T_7
1.200	1.269	1.361	1.369	1.393	1.649	1.652	1.719	1.763

TABLE LXII. A MULTIPLE RANGE TEST SHOWING NITROGEN DIFFERENCES BETWEEN SOILS FOR THIRD ALFALFA HARVEST DUE TO EFFECTS OF TREATMENTS

Data X 10

A. Standard Error of Means: $\sqrt{\frac{\text{Mean Square Error}}{\text{No. of items in treatments}}} = .056$

B. Shortest Significant Ranges:

p: (5% p-level)	(2)	(3)	(4)	(5)	(6)
R_p:	.172	.181	.186	.188	.190

C. Results:

"F"	"E"	"B"	"C"	"D"	"A"
1.171	1.325	1.337	1.527	1.554	2.017

Note: Any two means underscored by the same line are significantly different. Any two means underlined by the same line are not significantly different.

poor aeration and slow water infiltration and it was a poor soil for a greenhouse study. Soils "A", "C", and "D" physically were very good soils, and Soils "A" and "B" were slightly better physically than Soil "D". Part of the increased nitrogen uptake on these soils could be due to increase in yield.

V SUMMARY AND CONCLUSIONS

This thesis reports the results of a greenhouse experiment conducted at Oklahoma State University in 1956 and 1957. The objectives of this experiment were twofold. The first objective was to determine the relative response of alfalfa to fertilizer treatments. The second objective was to determine if any relationship existed as to treatment response between soils. The eastern one-half of Oklahoma was divided into three geographical regions: Central, Northeast, and Southeast. One soil from each region represented a prairie soil, whereas, the other soil from each region was a former timbered soil. The soils from each region were dissimilar in their chemical and physical properties. These soils were analyzed in the laboratory and then placed in greenhouse pots, which were arranged in a completely randomized split plot design. Each soil was subjected to nine fertility treatments.

Alfalfa plantings were made on November 21, 1956. The plants were weighed and analyzed in the laboratory. There was a significant difference at the five percent probability level as to forage yield and nutrient element uptake. Both rock phosphate and superphosphate gave an increase in yield and nutrient element uptake when compared to a phosphorus treatment.. There was no significant difference between treatments 2 and 4; therefore, the assumption was valid that fifty percent of the phosphorus in rock phosphate is available to alfalfa, as both treatments affected yields equally well. Pots containing treatments 5 and 7 produced the greatest amount of alfalfa forage. The difference between treatments 4 and 5 or 6 and 7 as to alfalfa forage yield can be attributed directly to the addition of calcium.

The purpose of this experiment was to evaluate sources of phosphorus; however, the data obtained in this experiment indicates that both phosphorus and calcium were essential for alfalfa production on these soils. Increased yields and nutrient uptake occurred with the addition of calcium carbonate. There was no depressive interaction between rock phosphate and calcium carbonate.

Superphosphate was found to provide more phosphorus to alfalfa than rock phosphate, when they were applied on an equivalent basis as in treatments 2 and 4. Treatment 4 (superphosphate 625 lbs.) and treatment 6 (rock phosphate 1500 lbs.) were not significantly different as to phosphorus uptake; therefore, four times as much total P_2O_5 from rock phosphate than from superphosphate was required to provide an equivalent amount of phosphorus uptake by alfalfa. Forage yield and nutriend uptake was greatest from treatments 5 and 7.

There was a significant difference as to calcium, magnesium, potassium, and nitrogen uptake as affected by treatments. The greatest uptake of these elements occurred on pots contining both calcium and phosphorus as in treatments 1, 3, 5, 7, and 9.

Treatment 8 (rock phosphate and superphosphate) was found to be inferior to both rock phosphate and superphosphate alone as a fertility treatment on these soils.

A significant difference between soils occurred as to forage yield and chemical composition. For the three harvests Soil "A" was superior to the other soils in alfalfa yield and chemical composition. Soil "D" was the most responsive timbered soil, and this soil ranked second to Soil "A" in total forage yield, phosphorus uptake, and nitrogen uptake. Soil "E", which had the highest chemical potential, did not respond as well to fertilization as some of the other soils. The low response of this soil can be attributed to its poor physical condition which decreased aeration and water infiltration. Soils "B" and "F", timbered soils, were less responsive to fertility treatments than the other soils. Their poor fertility response can be attributed to their low chemical capabilities. Forage production and elemental uptake was greater for the prairie soils than for the wooded soils, with the exception of phosphorus. The wooded soils were more permeable than the prairie soils; therefore, a faster breakdown of the phosphate fertilizers probably occurred in these soils. No statistical relationship existed as to geographical regions; however, based upon total yields and nutrient uptake the geographical regions in descending order were as follows: Central, > Northeast, > and Southeast. Northeast and Southeast regions were reversed as to potassium uptake.

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VII APPENDIX

PROFILE DESCRIPTION OF KIRKLAND SILT LOAM (SOIL A)

This sample was taken from the northeast portion of the Oklahoma State University agronomy farm in plot 5100. This soil occupies a very gentle plane to weak concave south-facing slope and is closely associated with Bethany silt loam. The slope is about one percent. Cotton was being grown on this soil.

The soil profile is described as follows:

A_{1p}	0-8"	Grayish-brown (10 YR 4.5/2; 3.5/2, m) loam or silt loam; weak medium granular; friable; permeable; pH 5.2; a few fine pores; rests abruptly on the layer below.
B_{2-1}	22-32"	Dark grayish-brown (9 YR 4/2; 3/2, m) clay; moderate fine blocky; very firm; sticky and plastic when wet; very slowly permeable; pH 5.4; sides of peds are varnished and have strong clay films; grades through a 4" transition to the layer below.
B_{2-2}	22-32"	Dark grayish-brown (10 YR 4/2; 3/2, m) clay; weak angular blocky; very firm and compact; very slowly permeable; pH 5.8; occasional fine black pellets; a few strong brown specks about tiny root holes; many fine calcium carbonate concretions below 24 or 26"; peds have a weak shine when moist; grades through a 3" transition to the layer below.
B_3	32-42"	Brown (7.5 YR 5/4; 4/3, m) light clay; weak medium blocky; firm or very firm; very hard when dry; pH 7.0; occasional black pellets and $CaCO_3$ concretions; sides of peds have weak coations of dark brown (7.5 YR 4/2, m); grades to the layer below.
C_1	42-52"	Reddish-brown (5YR 5/4; 4/4, m) heavy silty clay loam or light silty clay much like the layer above; pH 7.0; occasional large $CaCO_3$ concretions and black ferruginous films; grades to the layer below.
C_2	52-64"	Reddish-brown (3.5 YR 5/4; 4/4, m) silty clay loam splotched with one percent of red (2.5 YR 4/6) has occasional light gray streaks; weak irregular blocky; firm; slowly permeable; pH 7.0; occasional fine black pellets and fine concretions of $CaCO_3$; changes little to greatest depth sampled.

PROFILE DESCRIPTION OF STEPHENVILLE LOAMY FINE SAND (SOIL B)

This sample was taken from the SE¼ of SW¼, Section 8, Township 16 North, Range 2 East in Logan County. The site occupies a gently sloping ridge position. The surface is convex with a two percent gradient. The site at which this profile was taken is an old abandoned field that has grown up in weeds and has scattered clumps of blackjack oak vegetation.

The profile description is as follows:

A_{1p}	0-6"	Grayish-brown (10 YR 5/2; 4/2, m) loamy fine sand; weak granular and friable; permeable; grades to the layer below; pH 6.2.
A_2	6-10"	Light brown (7.5 YR 6/4; 5/4, m) light fine sandy loam; nearly structureless, porous, and permeable; rapidly permeable; grades thru a thin reddish-brown sandy clay loam transition to the layer below.
B_2	10-24"	Reddish-brown (4 YR 5/4; 4/4, m) sandy clay with weak medium subangular blocky firm; hard when dry; many root holes and fine channels; grades to the layer below.
C_1	24-38"	Red sandy clay loam with thin seams of partly weathered reddish sandstone; occasional root holes and channels; ferruginous films; grades to the layer below.
D_1	38-40"	Red (10 R 4/6) soft, fine-grained sandstone which is streaked in the interior or cleavage planes with black films. This sandstone is thinly banded and contains some silty shale.

PROFILE DESCRIPTION OF PARSONS SILT LOAM (SOIL C)

A soil sample was taken from the Welch FFA Farm located .55 mile south of Highway 59 from the southeast corner of Welch. The landscape is weak concave to plane. There was a one percent gradient at the site. This tract of land has been used as a small grains test plot.

A description of this soil is as follows:

A_{1p}	0-9"	Grayish-brown (10 YR 5/2; 3/2, m) silt loam; moderate medium granular; friable, porous and permeable; pH 5.1; occasional black pellet and silt stone pebble; grades to the layer below.
A_2	9-13"	Pale brown (10 YR 6/3; 4.5/3, m) light silty clay loam; moderate medium subangular blocky and weak prismatic; pH 5.8; slightly firm moist; many dark brown spots up to ½" in diameter; many fine pores; root holes and worm casts; rests on the layer below.
B_{2-1}	13-22"	Grayish-brown (10 YR 4/2; 3/2, m) clay; moderate medium blocky; very firm; very slowly permeable; pH 5.8; sides of peds are shiny; many fine reddish-brown and red mottles; a few soft black pellets and dark brown spots; grades to the layer below.
B_{2-2}	22-34"	Gray (10 YR 6/1; 5/1, m) clay with ten to twenty percent mottling of red which is mostly in streaks lining former cleavage planes; many fine black pellets and soft ferruginous films; weak medium blocky; very firm; very slowly permeable; compact and very hard dry; pH 5.5; grades to horizon below.
B_3	34-46"	Coarsely mottled light gray, red and brownish-yellow clay containing ferruginous films and soft pellets; weathered sandstone and siltstone pebbles; very firm and compact; pH 5.5; grades slowly to the layer below.
C	46-54"	Dark brown (7.5 YR 4/4) clay with thin to thick lenses of light gray clay; weak blocky to massive; no tendency to separate in old bedding planes; contains many black films and a few black pellets; weathered siltstone and fine-grained sandstone pebbles. No gypsum was noted; pH 5.7

PROFILE DESCRIPTION OF LINKER FINE SANDY LOAM (SOIL D)

A soil sample was taken at a site located in the SE¼ of the SE¼, Section 35, Township 19 North, Range 15 East, Wagoner County. The area from which the sample was taken had previously been farmed, but now the area is in weeds and other undesirable vegatation. The landscape is convex with a slope of five percent.

A description of the soil is as follows:

A_p	0-8"	Pale brown (10YR 6/3) light fine sandy loam; very friable; non-sticky; pH 5.7; grades through 2" of transition to layer below.
B_2	8-24"	Reddish-brown (5YR 5/4) light sandy clay; with a few medium red mottles; weak subangular blocky; sides of peds slightly darker than the interiors and represent weak clay skins; pH 5.7; contains a few fine pebbles and partly rounded fragments of soft weathered sandstone.
C	24-30"	Brown partly weathered sandstone with seams of strong brown sandy clay loam; pH 5.7. At about 30" this grades to a moderately hard slightly weathered sandstone.

PROFILE DESCRIPTION OF WILSON SILT LOAM (SOIL E)

A soil sample was taken from a site three-fourth mile southwest of Bokchito in Bryan County. The sampling site was located in the NW¼ of the NW¼, Section 28, Township 6 South and Range 11 East. This site is on convex sloping erosional upland with a gradient of two percent. There is a scattering of 1" to 3" quartzite pebbles on the surface. Oats was the last crop to be grown on this land.

The soil profile is described as follows:

A_{1p}	0-8"	Dark grayish-brown (10 YR 4/2; 3/2, m) silt loam; weak granular; friable; permeable; pH 5.4; many fine roots; rests sharply on the layer below.
B_1	8-11"	Dark grayish-brown (10 YR 4/2) silty clay loam slightly mottled with a brownish-yellow; friable; weak medium subangular blocky; some roots and worm casts; pH 6.0; grades into horizon below.
B_{2-1}	11-22"	Grayish-brown (10 YR 4/2) clay mottled with ten to twenty percent reddish-brown; compound weak coarse prismatic and moderate medium blocky firm; very hard dry; medium crumbly moist; pH 6.0; grades into horizon below.
B_{2-2}	22-42"	Grayish-brown (10 YR 4/2) clay; weak blocky; sticky and plastic wet; very hard dry; fine roots to lower depths; clay films on perpendicular planes; grades to horizon below.
B_{3C}	42-54"	Grayish-brown (10 YR 5/3; 4/3, m) crumbly clay mottled with yellowish-brown and specked with yellowish-red; occasional black concretions; and calcium carbonate accumulations; a few pockets of gypsum crystals.

PROFILE DESCRIPTION OF BOWIE LOAMY FINE SAND (SOIL F)

A soil sample was taken from a site one mile west of Bentley in Atoka County SW¼ of Section 7, Township 4 South, Range 12 East. This is in gently sloping erosional upland, which has a convex surface and a gradient of one and one-half percent. Corn was grown on this land in 1956.

The soil profile is described as follows:

A_{1p}	0-6"	Light gray (10 YR 8/2; 5/2, m) loamy fine sand; weak granular and friable; permeable; grades to the layer below; pH 6.2.
A_2	6-10"	Light brown (7.5 YR 6/4; 5/4, m) light fine sandy loam; nearly structureless, porous, and permeable; rapidly permeable; grades thru a thin reddish-brown sandy clay loam transition to the layer below.
B_2	10-24"	Reddish-brown (4 YR 5/4; 4/4, m) sandy clay with weak medium subangular blocky firm; hard when dry; many root holes and fine channels; grades to the layer below.
C_1	24-38"	Red sandy clay loam with thin seams of partly weathered reddish sandstone; occasional root holes and channels; ferruginous films; grades to the layer below.
D_1	38-40"	Red (10 R 4/6) soft, fine-grained sandstone which is streaked in the interior or cleavage planes with black films. This sandstone is thinly banded and contains some silty shale.

TABLE III. TOTAL WEIGHTS* OF THREE ALFALFA HARVESTS GROWN IN GREENHOUSE

Treatments	Soils "A"	"B"	"C"	"D"	"E"	"F"	Treatment Total
1.	74.9	32.9	59.6	53.4	34.9	43.4	299.1
2.	69.3	59.1	54.3	53.6	43.6	51.0	330.9
3.	82.3	65.1	68.7	66.5	60.8	52.5	395.9
4.	70.1	66.0	53.9	60.6	47.0	56.4	354.0
5.	111.4	68.0	64.2	72.5	76.3	58.0	450.4
6.	84.2	56.2	53.4	72.8	50.7	51.7	369.0
7.	95.6	65.5	74.9	77.1	71.8	60.8	445.7
8.	73.9	46.3	44.7	51.4	42.9	53.4	312.6
9.	90.5	55.9	65.7	66.2	69.0	43.8	391.1
Soil Totals	752.2	515.0	539.4	574.1	497.0	471.0	3348.7

*Weights reported herein are in grams forage yield per pot.

TABLE IV. TOTAL WEIGHTS* OF PHOSPHORUS IN GRAMS TAKEN UP BY THREE[1] HARVESTS OF ALFALFA FORAGE IN GREENHOUSE POTS

	Soils						
Treatments	"A"	"B"	"C"	"D"	"E"	"F"	Treatment Totals
1.	.188	.052	.098	.089	.044	.088	.489
2.	.153	.138	.122	.133	.096	.127	.769
3.	.152	.146	.147	.153	.099	.127	.824
4.	.166	.196	.123	.169	.109	.174	.937
5.	.270	.208	.167	.206	.155	.184	1.190
6.	.177	.142	.136	.192	.119	.138	.904
7.	.204	.151	.175	.190	.125	.142	.987
8.	.157	.117	.104	.136	.104	.144	.762
9.	.164	.132	.131	.151	.118	.113	.809
Soil Totals	1.561	1.282	1.203	1.419	.969	1.237	7.671

*Weights reported herein are grams phosphorus per pot.

[1]Harvests one through three were analyzed for phosphorus.

TABLE V. TOTAL WEIGHTS* OF CALCIUM IN GRAMS TAKEN UP BY THREE[1] HARVESTS OF ALFALFA FORAGE IN GREENHOUSE POTS

	Soils						
Treatments	"A"	"B"	"C"	"D"	"E"	"F"	Treatment Totals
1.	.870	.419	.848	.699	.528	.487	3.851
2.	.752	.768	.577	.556	.563	.579	3.795
3.	1.149	.907	1.000	.853	1.129	.658	5.696
4.	.689	.731	.671	.648	.598	.617	3.963
5.	1.337	.952	.934	.993	1.208	.700	6.124
6.	.812	.700	.576	.850	.618	.633	4.189
7.	1.345	.934	1.087	1.016	1.339	.763	6.484
8.	.692	.582	.486	.665	.542	.646	3.613
9.	1.339	.750	.983	.894	1.223	.562	5.751
Soil Totals	8.994	6.743	7.162	7.174	7.748	5.645	43.466

*Weights reported herein are grams per pot.

[1]Harvests one through three were analyzed for calcium.

TABLE VI. TOTAL WEIGHTS* OF MAGNESIUM TAKEN UP BY THREE[1] HARVESTS OF ALFALFA FORAGE IN GREENHOUSE POTS

	Soils						
Treatments	"A"	"B"	"C"	"D"	"E"	"F"	Treatment Totals
1.	.349	.171	.356	.258	.162	.188	1.484
2.	.342	.310	.352	.259	.198	.223	1.684
3.	.426	.344	.426	.308	.298	.231	2.033
4.	.336	.336	.384	.319	.217	.218	1.810
5.	.489	.369	.386	.363	.357	.242	2.206
6.	.404	.314	.360	.375	.230	.214	1.897
7.	.424	.356	.478	.370	.333	.250	2.211
8.	.358	.282	.307	.273	.201	.229	1.650
9.	.467	.318	.406	.334	.327	.195	2.047
Soil Totals	3.595	2.800	3.455	2.859	2.323	1.990	17.022

*Weights reported herein are grams magnesium per pot.

[1]Harvests one through three were analyzed for magnesium.

TABLE VII. TOTAL WEIGHTS* OF POTASSIUM IN GRAMS TAKEN UP BY THREE[1] HARVESTS OF ALFALFA FORAGE IN GREENHOUSE POTS

	Soils						
Treatments	"A"	"B"	"C"	"D"	"E"	"F"	Treatment Totals
1.	2.251	.971	1.353	1.404	1.054	1.213	8.246
2.	1.963	1.378	1.362	1.509	1.133	1.287	8.632
3.	2.235	1.539	1.464	1.486	1.610	1.313	9.647
4.	1.859	1.480	1.206	1.254	1.162	1.263	8.224
5.	2.874	1.375	1.265	1.249	2.004	1.331	10.098
6.	2.309	1.365	1.312	1.493	1.399	1.345	9.223
7.	2.500	1.510	1.395	1.476	1.858	1.506	10.245
8.	2.067	1.160	1.147	1.249	1.180	1.196	7.999
9.	2.309	1.317	1.352	1.448	1.898	1.146	9.470
Soil Totals	20.367	12.095	11.856	12.568	13.298	11.600	81.784

*Weights reported herein are grams potassium per pot.

[1]Harvests one through three were analyzed for potassium.

TABLE VIII. TOTAL WEIGHTS* OF NITROGEN IN GRAMS TAKEN UP BY THREE[1] HARVESTS OF ALFALFA FORAGE IN GREENHOUSE POTS

Treatments	Soils "A"	"B"	"C"	"D"	"E"	"F"	Treatment Totals
1.	2.230	1.003	1.905	1.721	1.026	1.433	9.318
2.	2.047	1.813	1.650	1.578	1.276	1.578	9.942
3.	2.536	1.956	2.298	2.060	1.800	1.608	12.258
4.	1.912	1.971	1.720	1.943	1.371	1.606	10.523
5.	3.463	1.971	2.131	2.325	2.282	1.736	13.908
6.	2.287	1.753	1.631	2.290	1.429	1.558	10.948
7.	2.935	2.016	2.514	2.419	1.988	1.765	13.637
8.	2.003	1.488	1.403	1.591	1.207	1.586	9.278
9.	2.721	1.741	2.118	2.068	2.006	1.326	11.980

*Weights reported herein are grams nitrogen per pot.

[1]Harvests one through three were analyzed for nitrogen.

TABLE IX. ANALYSIS OF VARIANCE FIRST HARVEST ALFALFA FORAGE YIELD

SOURCE	DF	SS	MS	F
Total	161	1205.90		
Main Plot	17	416.34	24.491	3.851*
Soils	5	340.02	68.004	10.692**
Error (a)	12	76.32	6.360	
Treatment	8	278.07	34.759	8.831**
Treatment X Soils	40	133.66	3.342	.849
Error (b)	96	377.83	3.936	

TABLE X. ANALYSIS OF VARIANCE SECOND HARVEST ALFALFA FORAGE YIELD

SOURCE	DF	SS	MS	F
Total	161	655.59		
Main Plot	17	242.05	14.238	3.628*
Soils	5	194.95	38.990	9.934**
Error (a)	12	47.10	3.925	
Treatment	8	159.60	19.950	13.452**
Treatment X Soils	40	111.56	2.789	1.881**
Error (b)	96	142.38	1.483	

TABLE XI. ANALYSIS OF VARIANCE THIRD HARVEST ALFALFA FORAGE YIELD

SOURCE	DF	SS	MS	F
Total	161	395.45		
Main Plot	17	165.69	9.746	8.37**
Soils	5	151.71	30.342	26.04**
Error (a)	12	13.98	1.165	
Treatment	8	87.57	10.946	13.17**
Treatment X Soils	40	62.37	1.559	1.88**
Error (b)	96	79.82	.831	

* Significant at 5% probability level
** Significant at 1% probability level

TABLE XVIII. ANALYSIS OF VARIANCE PHOSPHORUS IN FIRST HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	.9310		
Main Plot	17	.1284	.0075	5.067**
Soils	5	.1107	.0221	14.733**
Error (a)	12	.0177	.0015	
Treatment	8	.3731	.0466	15.553**
Treatment X Soils	40	.1481	.0037	1.233
Error (b)	96	.2814	.0030	

TABLE XIX. ANALYSIS OF VARIANCE PHOSPHORUS IN SECOND HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	38.06		
Main Plot	17	11.31	.665	2.794*
Soils	5	8.46	1.692	7.109**
Error (a)	12	2.85	.238	
Treatment	8	14.47	1.809	24.120**
Treatment X Soils	40	5.08	.127	1.693*
Error (b)	96	7.20	.075	

TABLE XX. ANALYSIS OF VARIANCE PHOSPHORUS IN THIRD HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	26.31		
Main Plot	17	9.96	.586	6.894**
Soils	5	8.94	1.788	21.035**
Error (a)	12	1.02	.085	
Treatment	8	8.81	1.101	19.316**
Treatment X Soils	40	2.06	.052	.912
Error (b)	96	5.48	.057	

* Significant at 5% probability level
** Significant at 1% probability level

TABLE XXVII. ANALYSIS OF VARIANCE CALCIUM IN FIRST HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	4344.88		
Main Plot	17	764.22	44.954	3.081*
Soils	5	589.13	117.826	8.075**
Error (a)	12	175.09	14.590	
Treatment	8	1539.35	192.419	13.253**
Treatment X Soils	40	647.53	16.188	1.115
Error (b)	96	1393.78	14.519	

TABLE XXVIII. ANALYSIS OF VARIANCE CALCIUM IN SECOND HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	1351.87		
Main Plot	17	263.46	15.498	2.706*
Soils	5	194.74	38.949	6.801**
Error (a)	12	68.72	5.727	
Treatment	8	562.51	70.314	30.413**
Treatment X Soils	40	303.94	7.599	3.287**
Error (b)	96	221.96	2.312	

TABLE XXIX. ANALYSIS OF VARIANCE CALCIUM IN THIRD HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	798.07		
Main Plot	17	197.41	11.612	4.956**
Soils	5	169.29	33.858	14.451**
Error (a)	12	28.12	2.343	
Treatment	8	273.50	34.188	18.816**
Treatment X Soils	40	152.70	3.818	2.101**
Error	96	174.46	1.817	

* Significant at 5% probability level
** Significant at 1% probability level

TABLE XXXVI. ANALYSIS OF VARIANCE MAGNESIUM FIRST HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	440.16		
Main Plot	17	168.81	9.930	14.667**
Soils	5	160.69	32.138	47.471**
Error (a)	12	8.12	.677	
Treatment	8	81.66	10.208	6.707**
Treatment X Soils	40	43.59	1.090	.716
Error (b)	96	146.10	1.522	

TABLE XXXVII. ANALYSIS OF VARIANCE MAGNESIUM SECOND HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	174.92		
Main Plot	17	84.58	4.975	7.584**
Soils	5	76.71	15.342	23.387**
Error (a)	12	7.87	.656	
Treatment	8	34.97	4.371	13.166**
Treatment X Soils	40	23.52	.588	1.771*
Error (b)	96	31.85	.332	

TABLE XXXVIII. ANALYSIS OF VARIANCE MAGNESIUM THIRD HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	102.62		
Main Plot	17	44.16	2.598	7.079**
Soils	5	39.76	7.952	21.668**
Error (a)	12	4.40	.367	
Treatment	8	17.86	2.233	9.751**
Treatment X Soils	40	18.65	.466	2.035**
Error (b)	96	21.95	.229	

* Significant at 5% probability level
** Significant at 1% probability level

TABLE XLV. ANALYSIS OF VARIANCE POTASSIUM FIRST HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	82.60		
Main Plot	17	30.54	1.796	4.402**
Soils	5	25.64	5.128	12.569**
Error (a)	12	4.90	.408	
Treatment	8	6.84	.855	2.388*
Treatment X Soils	40	10.89	.272	.760
Error (b)	96	34.33	.358	

TABLE XLVI. ANALYSIS OF VARIANCE POTASSIUM SECOND HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	55.95		
Main Plot	17	33.19	1.952	16.132**
Soils	5	31.74	6.348	52.463**
Error (a)	12	1.45	.121	
Treatment	8	5.78	.723	6.694**
Treatment X Soils	40	6.66	.167	1.546*
Error (b)	96	10.32	.108	

TABLE XLVII. ANALYSIS OF VARIANCE POTASSIUM THIRD HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	30.29		
Main Plot	17	19.33	1.137	13.221**
Soils	5	18.30	3.660	42.558**
Error (a)	12	1.03	.086	
Treatment	8	2.21	.276	5.307**
Treatment X Soils	40	3.76	.094	1.808*
Error (b)	96	4.99	.052	

* Significant at 5% probability level
** Significant at 1% probability level

TABLE LIV. ANALYSIS OF VARIANCE NITROGEN FIRST HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	138.74		
Main Plot	17	37.68	2.216	2.732*
Soils	5	27.95	5.590	6.893**
Error (a)	12	9.73	.811	
Treatment	8	32.40	4.050	8.020**
Treatment X Soils	40	20.14	.504	.998
Error (b)	96	48.52	.505	

TABLE LV. ANALYSIS OF VARIANCE NITROGEN SECOND HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	60.29		
Main Plot	17	23.79	1.399	4.305**
Soils	5	19.89	3.978	12.240**
Error (a)	12	3.90	.325	
Treatment	8	15.31	1.914	16.220**
Treatment X Soils	40	9.90	.248	2.102**
Error (b)	96	11.29	.118	

TABLE LVI. ANALYSIS OF VARIANCE NITROGEN THIRD HARVEST ALFALFA FORAGE

SOURCE	DF	SS	MS	F
Total	161	29.15		
Main Plot	17	12.79	.752	8.744**
Soils	5	11.76	2.352	27.350**
Error (a)	12	1.03	.086	
Treatment	8	6.15	.769	13.034**
Treatment X Soils	40	4.55	.114	1.932**
Error (b)	96	5.66	.059	

* Significant at 5% probability level
** Significant at 1% probability level

Figure 1. Calcium Titration Curves For Prairie Soils

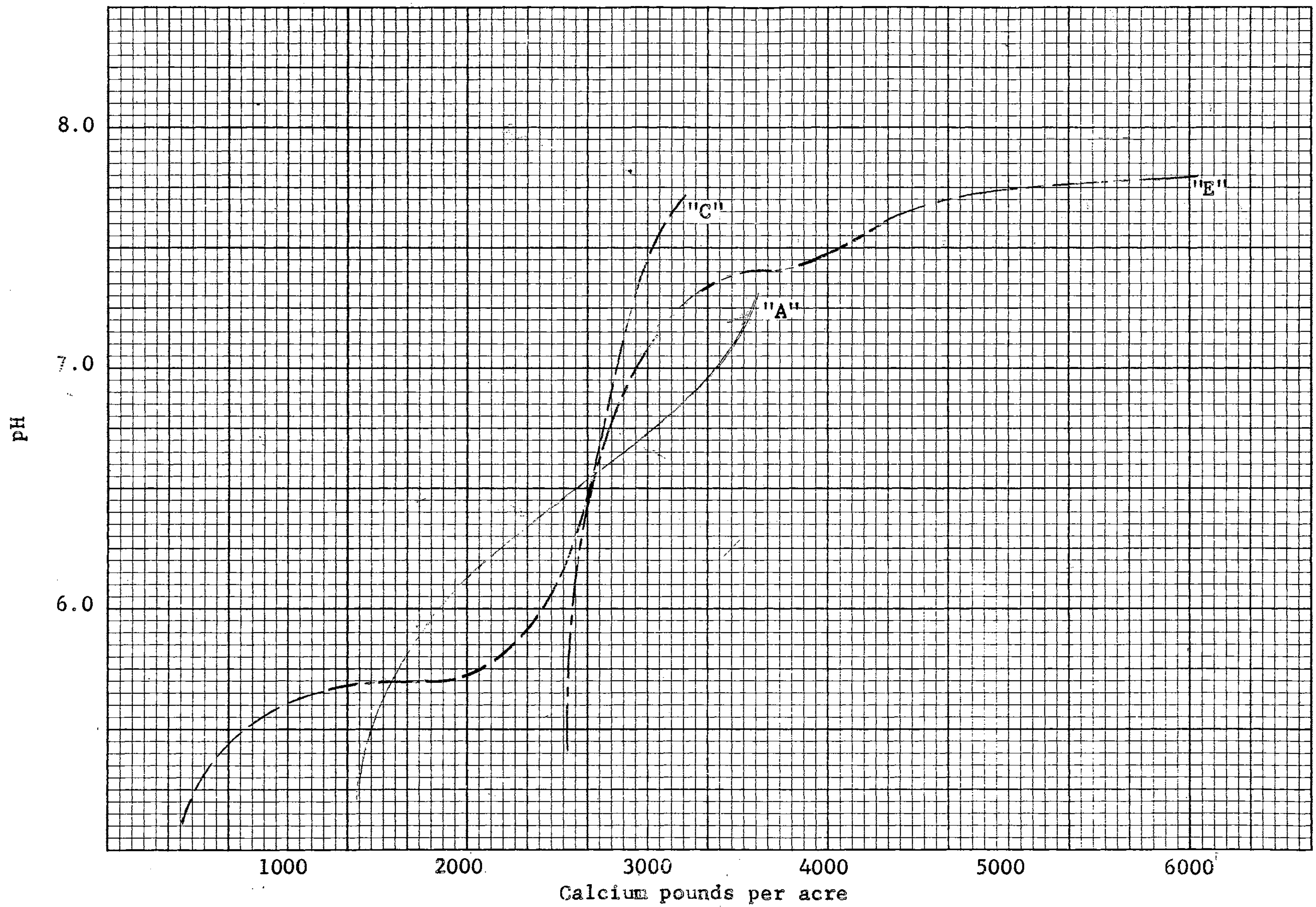
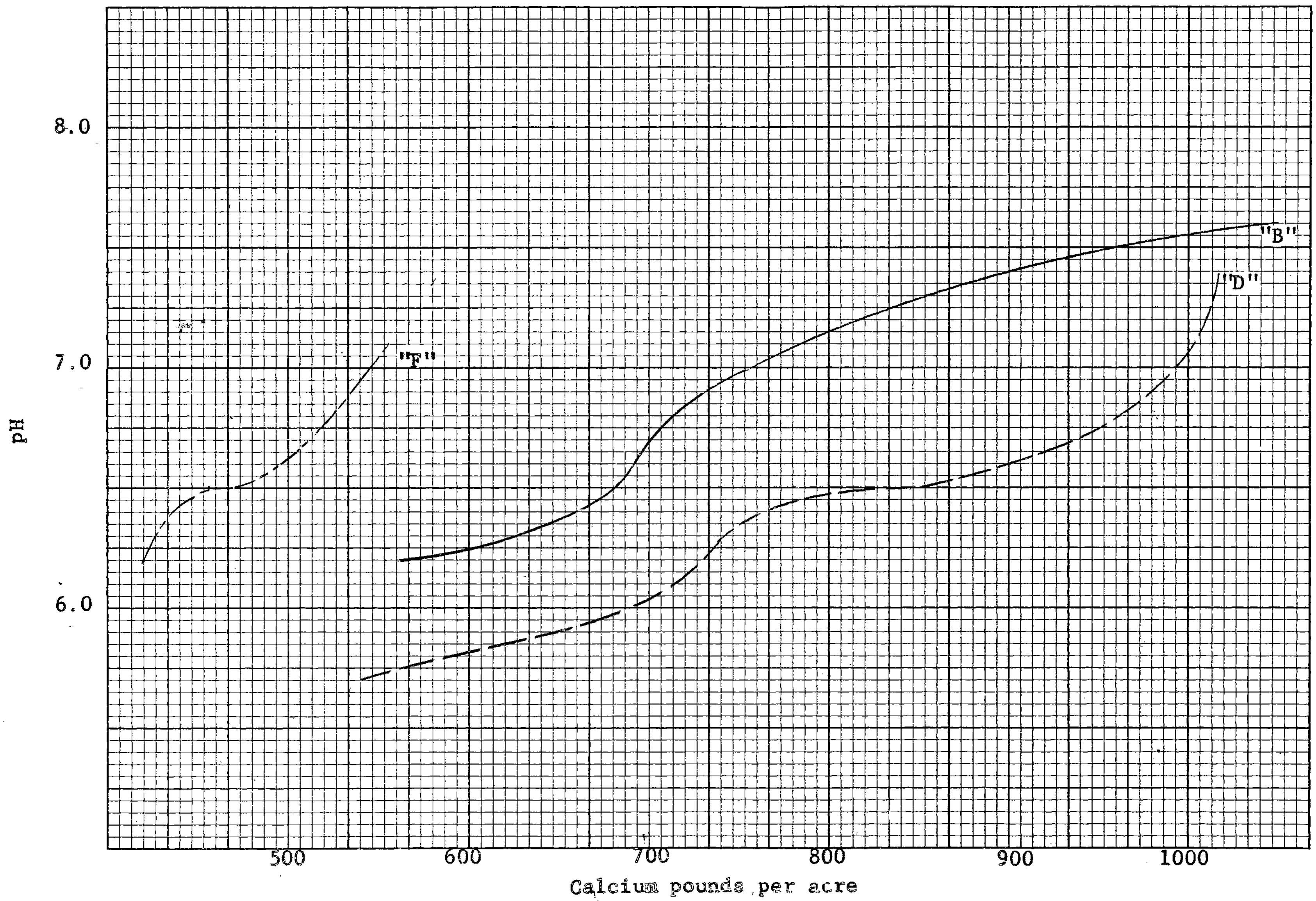


Figure 2. Calcium Titration Curves For Timbered Soils



VITA

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Master of Science

Thesis: EFFECT OF ROCK PHOSPHATE, SUPERPHOSPHATE, AND LIME ON YIELD AND COMPOSITION OF ALFALFA GROWN ON SIX OKLAHOMA SOILS

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