THE EFFECT OF SOIL REACTION AND APPLIED PHOSPHORUS ON THE PHOSPHATE AVAILABILITY OF FOUR OKLAHOMA SOILS

By

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Phosphorus has often been referred to as the "master key" to American agriculture. Under Oklahoma conditions, many of the low crop yields can probably be attributed to a lack of phosphorus. Causes for these phosphorus deficiencies are numerous. However, poor management practices probably prevail in the majority of cases. In Eastern Oklahoma, where the largest annual rainfall within the state occurs, many of the soils have been leached and cropped with no additions of lime and fertilizer. This has resulted in soils which are acid in reaction and very low in fertility.

Retention of phosphorus in difficultly available forms has been recognized for many years as a problem of great importance in agronomic research. Soils vary in their ability to fix applied phosphorus and the mechanisms responsible for this fixation no doubt vary with soils.

The objectives of this study were to determine the effect of soil reaction upon the availability of soil phosphorus and to compare three chemical methods of extracting phosphorus from soils. Although the literature contains a great number of papers concerning the problem of phosphate availability, there is still the need for information pertaining to specific soils. It was with this in mind that the author chose this problem.

CHAPTER II

REVIEW OF LITERATURE

Many valuable, agronomic studies have been undertaken because of a realization that a knowledge of the chemical behavior of phosphorus in soils is very important. It has long been known that soils have the ability to fix phosphate or retain applied soluble phosphate in difficultly available forms. In a system as complex as the soil, it is difficult to evaluate each factor properly and independently. As Murphy (24)[1] indicated, ". . . the term phosphate fixation carries no implication of the mechanism by which removal takes place or of the nature of the products formed." Generally, there are two types of reactions described in the literature on phosphate retention. These are fixation by precipitation and by adsorption.

Bradfield et al. (5) concluded that the fixation of phosphate ions over a wide range of reactions and concentrations was due to at least three distinctly different mechanisms. He believed that at pH values from 2.0 to 5.0 the retention was due chiefly to the gradual liberation of iron and aluminum ions and their reprecipitation as phosphates. Fixation on the surface of the clay particles was believed to predominate at pH values of 4.5 to 7.5. At pH 6.0 to 10.0, retention was largely by the divalent cations if present.

The fixation of phosphates in a pH range of 5.0 to 6.0 by a sodium clay was shown by Scarseth (33) and he suggested that the phosphate ion

[1]Figure in parenthesis refers to Literature Cited.

replaced a hydroxyl ion attached to an aluminum ion at the surface of the colloid. A reaction under a more slightly acid condition resulted in increased adsorption in clays containing exchangeable calcium and was thought to be due to a linkage of the phosphate to the calcium ions held in exchange positions. Fixation at low pH levels, 3.0 to 4.0, was explained by precipitation of phosphates by ions of iron and aluminum which came into solution under those conditions. Allison (2), working with clays purified by a biological reduction method, agreed with Scarseth (33) on the mechanism of phosphate retention under these conditions.

Metzger (23) provided evidence to support the idea that the phosphorus fixing capacity of acid prairie soils can be accounted for largely by precipitation phenomenon. He found a close correlation between the amount of the total Fe_2O_3 which was removed in dilute acid and the percentage reduction in phosphorus fixing capacity which occurred after this extraction. His data also indicated that the easily soluble aluminum in the soil is not as active as iron in fixing phosphorus.

Goethite fixed large quantities of phosphorus in a form that could not be extracted with sulfuric acid buffered at pH 3.0. By using X-ray methods the phosphates fixed by Goethite formed a new mineral with a different crystalline structure and thus indicated a chemical precipitation (10).

According to Heck (14), the fixation of phosphates is more dependent upon the state of hydration of iron and aluminum oxides rather than the amounts present in the soil solution. He found that yellow soils fixed more phosphorus than red ones, which would support the theory that fixation by iron is brought about largely by the hydrated oxides. This work was corroborated by Marias (21) who studied a number of natural iron and aluminum phosphates, and found that their solubility could be increased by heating to drive off the water of hydration.

Kittrick and Jackson (16) found that removal of extractable iron oxides from the soil greatly diminished the rate of reaction of phosphate with the soil, but reaction with the kaolinite portion was nearly half of the total. Synthetic colloidal iron oxide and aluminum hydroxide particles were produced analogous to the reactive surfaces responsible for the rapid initial reaction of phosphate with soil minerals. Electron microscope observations of these minerals in contact with a phosphate solution disclosed the formation of separate-phase phosphate crystals in a few minutes by the mechanism of solution-precipitation. These experiments suggested that the solution-precipitation mechanism is important in phosphate fixation in soils.

The hydrous oxides of aluminum and iron are effective in combining chemically with H_2PO_4 ions at low pH levels because the stability of basic metal phosphate is greater than the hydrous oxide at these lower pH values according to Swenson et al. (37).

A number of mechanisms for reactions involving phosphate uptake by clays have been proposed, but no single mechanism appears sufficient to cover all cases. The general practice at the present time is to group those reactions occurring at the colloid surface and resulting in a concentration at the interface as adsorption reactions.

Murphy (24) explained retention of phosphate by kaolinite and kaolinitic soils by an exchange of added phosphate with hydroxyl ions of the hydroxyl layers in the kaolinite crystal lattice. This belief was supported by Stout (36) who found that adding phosphate to ground kaolinite changed the X-ray pattern and the water formed from the released hydroxyls was equivalent to the amount of phosphate adsorbed. In contrast, Seiling (34) concluded that the chief reaction was not between phosphate and kaolinite, but between a product of the grinding, "possibly a hydrous alumina such as AlOOH," and that hydroxyls were released during the reaction. Kaolinite can be decomposed by the addition of concentrated phosphate solutions. Some type of aluminum phosphate compounds plus free silica were formed (17).

According to Hibbard (15), in alkaline and calcareous soils, native phosphorus occurs chiefly in the inorganic forms of hydroxyapatite, fluorapatite, chlorapatite, wagerite, wavellite and as organic compounds. The results of various investigators (7, 11, 22) agree generally that phosphate solubility in calcareous soils is at a minimum in the pH range from 7.0 to 7.5 and increases with either an increase or decrease in pH from this particular range.

It is generally accepted that lime has the ability to increase the availability of the phosphorus from added phosphates, as well as the native forms, especially in acid soils high in iron and aluminum. However, Neller (25) conducted a greenhouse experiment on a Rutlege fine sand and reported no significant effect on the percentage of labeled phosphorus taken up by oats when enough lime was added to raise the pH from 5.61 to 6.76. Di-sodium phosphate and superphosphate were used as the phosphorus carriers in these tests. Lime also significantly reduced the total phosphorus content of the oats.

The acid sandy soils of Florida are characterized by the leaching of phosphorus from the surface layers. Neller et al. (26) found that when the pH was low as 4.5 practically all of the phosphorus from superphosphate was leached from the surface three inches of soil in approximately one year. Liming at a rate sufficient to raise the pH to 5.7 caused a retention of about three-fifths of the phosphorus added in soluble phosphate fertilizers such as superphosphate.

To determine the effect of soil reaction on the availability of phosphorus, MacLean and Cook (20) carried on an experiment in which alfalfa was grown in pot tests. The yields of alfalfa grown without phosphorus fertilizer tended to increase with increased pH up to a pH of approximately 7.5, which was the highest level used. Where phosphorus was added, there was evidence that the optimum reaction for alfalfa was reached, in most instances, at pH values of 6.5 to 7.0. Application of phosphorus resulted in appreciable increases in the yields of alfalfa. These workers believed that at the higher pH levels the smaller response to applied phosphorus would indicate that the native phosphorus was made more available to alfalfa even when lime was applied to raise the pH of the soil to slightly above neutrality.

Other workers (3, 9, 12) have also found that liming the soil resulted in increased amounts of available phosphorus within soils. Parker and Tidmore (28) found that liming increased the phosphorus content of the soil solution and of the extracts from soils receiving acid phosphate or basic slag. The influence of lime on the solubility of rock phosphate was not appreciable. In some cases it apparently increased and in others reduced the availability of rock phosphate. Liming had a very decided depressing effect on the solubility of phosphorus in steamed bone meal.

It has been suggested by Albrecht and Smith (1) that there exists a more complex process within the plant rather than a simple solubility situation in the soil, when the saturation of the soil with calcium increases the amount of phosphorus absorbed. They further state that liming becomes a matter of effectively feeding calcium to the plant and of aiding it in obtaining phosphorus, rather than one of modifying the hydrogen-ion concentration of the soil. They found that calcium played a significant role in increasing phosphorus utilization by both legume and non-leguminous crops.

MacIntire (18) and MacIntire and Hatcher (19) have advanced an explanation of what happens to superhphosphate in limed soils. They concluded that any part of superphosphate, incorporated into a limed soil, not fixed or used by the plant, would be reverted to a fluorphosphate, $Ca_{10}F_2(PO_4)_2$, which characterizes raw rock phosphate. Chalk fragments applied over a century ago on the Broadbalk field at the Rothamsted Experiment Station, showed an increase in phosphorus and fluoride percentages from 1881 to 1944 (8). The residue gave an X-ray powder diagram of apatite. The extent to which this phenomenon may become of practical importance is not known at the present time.

Many extracting agents have been used in measuring available phosphorus in soils and they have been successful to a variable degree. To be successful, a soil test must employ an extracting solution which meets the following requirements (6).

1. It must extract the total amount (or a proportionate amount) of the available forms of the nutrient from soils with different properties.
2. It must measure with reasonable accuracy the amount of the nutrient in the extract.
3. Its action must be fairly rapid.

Relatively few chemical methods, employing either alkaline or acid reagents, have been proposed for extracting the readily available phosphorus from both acid and alkaline soils. Olsen et al. (27), working with soils whose range in pH was from 5.0 to 7.6, found that $NaHCO_3$ removed about fifty percent of the surface or exchangeable phosphorus from the soil. The data presented by these workers indicated that the $NaHCO_3$-soluble phosphorus was closely related to the forms of phosphorus in the soil which in turn were highly correlated with the amount of phosphorus available to plants.

One of the objectives in research on soil tests has been to eliminate or diminish the secondary precipitation reac tions which may develop during a dilute acid extraction. Secondary precipitation reactions may occur with extractants which increase the hydrogen ion activity of the calcareous soil-water system because of the accompanied increase in the action of calcium ions. Since the solubility of phosphate may be increased in this system with a decrease in the calcium ion activity, the secondary precipitation reactions should be largely eliminated if an extractant decreases the calcium ion activity. It was believed by Olsen et al. (27) that the Bray method evidently is less subject, on calcareous soils, to interfering secondary reactions due to its short extraction period.

CHAPTER III

MATERIALS AND METHODS

The data presented in this thesis includes both greenhouse and laboratory studies. The objective was to determine the availability of phosphorus under adjusted and unadjusted soil reactions and to compare three chemical methods of phosphorus extraction.

Soils Used in Greenhouse and Laboratory Studies

The four soils selected for these experiments encompass large areas of cultivated land in Oklahoma. In choosing the soils, an attempt was made to obtain samples which represent distinct areas of the state.

Pullman Clay Loam

A bulk soil sample of this series was taken from a field two miles north and one and one-half miles west of Goodwell, Texas County, Oklahoma.

The Pullman series[1] is a deep Reddish Chesnut soil with a brown compact clayey subsoil developed from fine-textured calcareous sediments. This series occupies level areas on the High Plains of northwestern Texas and adjoining states. Topography is nearly level upland on the High Plsins with gradients of zero to two percent, but slopes of more than one-half percent constitute only a minor proportion. Drainage is slow both externally and internally. The native vegetation is composed chiefly of buffalo and blue grama grasses. These soils are largely dry farmed to winter wheat.

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[1]Established Series, Division of Soil Survey, BPISAE, ARA, U. S. Dept. of Agr. Unpublished data.

Bowie Sandy Loam

A bulk sample of this series was obtained from a field near Bently, Atoka County, Oklahoma.

The Bowie series[1] consists of a Yellow Podzolic soil having friable subsoil which is yellow in the upper portion, but splotched or mottled with red in the lower. The parent materials are acid moderately sandy earths of the Gulf Coastal Plain. Topography is nearly level to gently rolling upland with gradients mostly between one and four percent, but ranging as high as ten. Drainage is fully adequate and favorable for all common crops. Native vegetation consists of pine-oak forest giving way to the west, at about the 40 inch rainfall line, to post oak and blackjack. Approximately 50 percent of these soils are in cropland. A considerable amount of the cleared acreage is in pasture or idle. The soils have a low inherent fertility, but have favorable physical characteristics and are responsive to good management practices.

Parsons Silt Loam

A bulk soil sample of this series was collected four miles notrh and three and one-half miles east of Pryor, Mayes County, Oklahoma.

The Parsons series[2] is a rather light-colored Planosol of the Prairie and Reddish-Prairie zones which is developed from silty and clayey materials weathered from non-calcareous gray and brown shales. Topography is nearly level to moderately sloping uplands. Grandients range from about one to four percent. Surface runoff is medium to low and the permeability is slow to very slow. Crops are subject to drought on these soils. Native vegetation consists of prairie grasses, chiefly bluestems. The

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[1,2]Established series, Division of Soil Survey, BPISAE, ARA, U. S. Dept. of Agr. Unpublished data.

principal cultivated crops consist of oats, wheat, flax and sorghums. Some corn is grown, but because of the low moisture capacity of the soil body, yields are uncertain.

Kirkland Silt Loam

A bulk sample of this series was taken from a field three miles east of Billings, Noble County, Oklahoma.

The Kirkland series[1] occurs on a slightly acid, moderately to highly fertile Reddish Prairie soil. It is characterized by A horizons which are less than fourteen inches thick, abrupt to clear boundaries between the A and B horizons, and brownish claypans not overlain by a distinct "gray layer." This series is developed from alkaline, mostly reddish clays and shales, commonly of the Permian geologic period. Topography is nearly level to very gently undulating upland which is subject to erosion. The slope gradients are mostly less than two percent. The drainage is slow to moderate from the surface and very slow internally. However, this soil is adequate for common field crops. Native vegetation consists of tall prairie grasses which are largely replaced by short grasses in pastured areas. Crops grown in cultivated areas are oats, wheat, cotton and sorghums.

Greenhouse Procedure

In this study two-gallon, glazed, non-porous pots were used for the cultures. A sufficient quantity of soil was placed in each container, so that the surface was within approximately one and one-half inches of the top of the jar. The amount of soil required per pot for each of the

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[1]Established series, Division of Soil Survey, BPISAE, ARA, U. S. Dept. of Agr. Unpublished data.

four soils used was as follows: Bowie and Pullman, 7,257.6 grams; Kirkland, 5,896.8 grams; and Parsons, 6,804 grams. The physical and chemical properties of the four soils used in this study are found in Tables 1 and 2.

Treatment applications were made on March 21, 1955, with the exception of the liming material which had been applied two weeks previously. All the treatments were added in the form of solutions. The desired amount was measured from a burette. Treatments were placed in a ring two inches below the surface and one inch from the wall of the container.

U. S. 13 variety of corn, Zea mays, was grown as the test crop. This variety was selected because it matures early and has the ability to make a rapid vegetative growth. This was desirable since the vegetative growth was taken as a measure of yield. The corn was planted in the pots on March 24, 1955. Six seeds were planted in each jar, but were thinned back to four plants after a complete stand was assured. The pots were arranged in a randomized block design along the west bench in the greenhouse. Distilled water was used to water the cultures throughout the entire growth period.

Height measurements were made on April 13, 1955, and May 7, 1955. The plants were measured from the base of the plant to the tip of the highest leaf held in a vertical position. Results of these measurements were recorded. Fifty-eight days after planting, pictures were made of the vegetative growth of the corn plants on the four soils. All pictures were taken of the first replication.

On May 21, 1955 all the plants were harvested. The plant samples were placed in a drying oven at 60^{0} C. for 72 hours. Weights of the dry vegetative material were taken. The samples were then ground with a

Table 1. Analyses of soils used in greenhouse and laboratory studies.

Soil Type	Soil Texture[1] % Sand	% Silt	% Clay	Soil pH [2]	Total % N [2]	% O.M.[2]	% Total P[2]
Parsons Silt Loam	14.75	64.75	20.50	4.8	0.10	1.713	0.015
Pullman Clay Loam	24.75	40.75	34.50	7.1	0.12	1.811	0.042
Kirkland Silt Loam	18.75	56.75	24.50	5.3	0.09	1.687	0.014
Bowie Sandy Loam	70.75	22.75	6.50	5.3	0.03	0.503	0.008

(% $CaCO_3$)[3] in the Pullman soil = 1.0

1. Determined essentially by the method of Bouyoucos (4).
2. Determined by the methods of Harper (13).
3. Determined by the rapid titration method of Piper (31).

Table 2. Analyses of soils used in greenhouse and laboratory studies (Cont'd.)

Soil Type	Milliequivalents per 100 grams of soil: Cation Exchange Capacity[1]	K[2]	Ca[2]	Mg[2]	Na[2]	Total Bases[4]	H[3]
Parsons Silt Loam	8.671	0.208	2.669	1.292	0.272	3.726	4.945
Pullman Clay Loam	24.667	1.779	12.813	4.453	0.245	23.092	1.575
Kirkland Silt Loam	15.386	0.461	5.375	2.979	0.245	10.166	5.220
Bowie Sandy Loam	1.543	0.112	0.563	0.575	0.077	1.163	0.380

1. Determined essentially by the method of Peech, et al. (29).
2. Determined by the Beckman Spectrophotometer.
3. Determined by difference between the exchange capacity and total bases.
4. Determined by the method of Russel and Stanford (32).

Wiley mill and stored in one-half pint containers. The samples were analyzed for nitrogen and phosphorus content according to the methods of Harper (13). All yield data plus the nitrogen and phosphorus percentages of the plant material were analyzed statistically by the randomized block method reported by Snedecor (35).

The soils were air-dried in the pots and samples were taken for laboratory analysis. One soil sample from each treatment within the three blocks was selected at random. Thus, there were 24 soil samples for the laboratory tests.

Treatments of Greenhouse Soils

In adjusting the reaction of the Pullman soil, 0.05 Normal hydrochloric acid was used as the leaching agent. Two hundred and fifty grams of soil were placed in a series of several small glass tubes which were set up in the laboratory. Different amounts of acid were then added to these tubes. The excess acid was leached out with distilled water until no chlorides could be detected in the leachate with silver nitrate. The volume of acid required to reduce the pH value to 6.5 was taken as the correct one.

Several large zinc cylinders were lined with roofing paper and used as containers for the leaching of the bulk soil for the greenhouse experiment. The amount of hydrochloric acid added was based on the results of the laboratory tests. The excess acid was again removed with distilled water until no chlorides were present in the leachate. When the leaching had been completed the soil was taken from the cylinders and spread out in a thin layer on the greenhouse bench to dry. After the soil had been dried, it was pulverized and thoroughly mixed before being placed in the pots. The pH of 6.5 was verified by checking a sample of the leached, dry soil with a Beckman glass electrode pH meter.

Calcium acetate, $Ca(C_2H_3O_2)_2 \cdot H_2O$, was employed as the liming material because of its high solubility in water. Enough calcium acetate was added to the Bowie, Kirkland, and Parsons soils to bring the base saturation of these soils to eighty five percent of the total cation exchange capacity. These calculations were based on total bases present, according to the method of Russel and Stanford (32) and the cation exchange capacity. (Table 2).

Phosphorus was applied at three rates. They were zero, twenty, and forty pounds of P_2O_5 per acre. Reagent grade monocalcium phosphate, $CaH_4(PO_4)_2 \cdot H_2O$, was used as the phosphorus carrier. One hundred pounds per acre of reagent grade ammonoum nitrate, NH_4NO_3, was supplied to all cultures in an attempt to eliminate nitrogen as a limiting growth factor. As the experiment progressed, it became apparent that the plants did not have a sufficient amount of available nitrogen. Therefore, on May 5, 1955, an additional 100 pounds per acre of ammonium nitrate was added to all pots. Potassium chloride, KCl, was added to the Bowie soil treatments at the rate of one hundred and fifty pounds per acre, in an attempt to bring the potassium level of this soil to a comparable level with the other three soils.

All possible combinations of soils and treatments were utilized in this experiment and this gave a complete factorial design which was replicated three times. The following is a summary of soils and treatments:

Four soils - Bowie, Parsons, Pullman and Kirkland

Two soil reaction levels - unadjusted and adjusted

Three phosphorus levels - Zero, twenty and forty pounds of P_2O_5 per acre.

Laboratory Procedures

Three chemical methods were used in measuring the easily soluble phosphorus in both the original soils and those which had been subjected to cropping under greenhouse conditions. The methods employed were those of Olsen, et al. (27), Bray (6) and Harper (13).

Olsen's method is based on an extracting agent of a 0.5 molar $NaHCO_3$ solution adjusted to pH 8.5 with NaOH. The color was developed by reducing the ammonium phospho-molybdate complex with dilute stannous chloride. Color intensity was determined by the Fisher Electrophotometer. The values obtained were then converted to parts per million of phosphorus by consulting a previously prepared standard curve.

The extraction was made with 0.03 N. ammonium fluoride in a solution of 0.025N. hydrochloric acid, when Brays' method (6) was used. Ammonium molybdate was the complexing agent and 1-amino-2-napthol-4-sulfonic acid served as the reducing agent. The percent transmission was determined by a Cenco Photelometer. The readings were changed to parts per million by means of a standard curve.

Harpers' method (13) of determining available phosphorus has a 0.1 Normal acetic acid solution as the leaching agent. Color was developed by using ammonium molybdate as the complexing agent and stannous chloride as the reducing agent. The color intensity was determined by using a Fisher Electrophotometer and the values converted to parts per million by consulting a standard curve.

In the extractable iron determination, Peech and English's method (3) was employed. A 0.73 Normal solution of sodium acetate, $NaC_2H_3O_2$.

$3H_2O$, in a 0.52 Normal acetic acid solution was the extracting agent. The ferric iron was reduced by the addition of hydroxylamine hydrochloride and color was developed by the addition of o-phenanthroline. The percent transmission was measured by a Cenco Photelometer and the values were changed to parts per million by consulting a standard curve. It is believed that the greater part of the iron extractable by this method represents the water-soluble and exchangeable forms.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the first height measurements of the corn plants, 20 days after planting, are reported in Table 3. They indicated a greater growth rate with an increase in rate of phosphate applications on all soils except the Pullman. There appeared to be a slight decrease in height of plants when phosphorus was added to this soil. This would tend to indicate that phosphorus was not a limiting factor of growth on the Pullman soil. Adjustment of the soil reaction had no appreciable influence on the height of the corn growing on the Bowie, Kirkland and Pullman soils. However, the plants on the Parsons soil showed a noticeable height increase when the check and lime alone treatments were compared. The statistical analysis, given in Table 4, showed significant differences among soils, phosphorus levels and soils-phosphorus levels interaction.

The second height measurements of the corn, 44 days after planting, found in Table 5 was considerably more erratic than the first one. However, the plants grown on the Kirkland soil had established a trend which they held throughout the remainder of the experiment. These corn plants showed a greater growth response to 20 pounds of P_2O_5 per acre than the 40 pound rate when the soil reaction was unadjusted. Under adjusted conditions, the height of the plants was greatest at the heaviest phosphate rate. There was a slight reduction in height of the corn with added increments of phosphorus on the Bowie, Pullman and Parsons soils when the soil reaction was unchanged. Reduction in

Table 3. Effect of soil reactions and phosphorus levels on the height of corn, 20 days after planting, grown on four soils in the greenhouse.

Treatments	Soils			
	Bowie	Kirkland	Pullman	Parsons
P_o	24.79*	21.40	28.21	19.71
P_1	27.54	25.44	26.54	24.86
P_2	28.33	26.42	25.00	25.75
A P_o	23.23	20.54	28.19	22.29
A P_1	27.31	22.27	27.39	24.94
A P_2	28.48	26.33	26.15	25.04

*Height measurements are reported in inches. Each figure represents an average of four plants in each pot and an average of three replications.

Key to Treatments

P_o - 0 pounds P_2O_5 per acre

P_1 - 20 pounds P_2O_5 per acre

P_2 - 40 pounds P_2O_5 per acre

A - Adjusted soil reaction

Table 4. Analysis of variance for height of the corn, 20 days after planting, grown on four soils in the greenhouse.

Source of variation	d.f.	S. S.	M. S.
Total	71	621.07	
Blocks	2	16.58	8.29
Treatments			
Soils	3	164.40	54.80**
Levels of phos.	5	112.91	22.58**
Soils x Levels	15	162.81	10.85**
Error	46	164.37	3.57

**Indicates significance at the one percent level of confidence.

Table 5. Influence of soil reactions and phosphorus levels on the height of corn plants, 44 days after planting, grown on four soils in the greenhouse.

Treatments	Soils: Bowie	Kirkland	Pullman	Parsons
P_0	52.71*	44.50	49.56	48.81
P_1	46.00	45.92	47.33	45.88
P_2	43.17	43.04	45.61	45.88
A P_0	48.25	35.92	46.92	48.96
A P_1	46.84	47.10	45.29	51.27
A P_2	46.42	49.48	47.15	49.86

*Height measurements are reported in inches. Each figure represents an average of four plants in each pot and an average of three replications.

Key to Treatments

P_0 - 0 pounds P_2O_5 per acre

P_1 - 20 pounds P_2O_5 per acre

P_2 - 40 pounds P_2O_5 per acre

A - Adjusted soil reaction

Table 6. Analysis of variance for height of corn plants, 44 days after planting, grown on four soils in the greenhouse.

Source of variation	d.f.	S. S.	M. S.
Total	71	1,198.03	
Blocks	2	35.15	17.58
Treatments			
Soils	3	162.24	54.08**
Levels of phos.	5	194.39	38.88**
Soils x Levels	15	388.33	25.89**
Error	46	417.92	9.09

**Indicates significance at the one percent level of confidence.

height of plants was extremely small with added phosphorus on the limed Bowie soil and completely absent on the Pullman and Parsons soils. The statistical analysis of the second height measurements, located in Table 6, again indicated significant differences among soils, levels of phosphorus, and soils-levels of phosphorus interaction.

The pictures of the vegetative growth of the corn plants, Figures 1 through 8, showed the influence of adjusted and unadjusted reactions in combination with three levels of phosphorus. The most striking differences were shown on the Kirkland soil, where the lime treatment alone caused a great decrease in the growth of corn plants.

Results of the vegetative yields of corn plants grown on the four soils used in the greenhouse study are shown in Table 7. No significant differences were found when the vegetative yields of plants from the Bowie, Pullman and Parsons soils were analyzed statistically. (Tables 8, 10, and 11). Although not statistically significant, there did seem to be a trend in vegetative yields of corn grown on the Pullman soil. When the applied phosphorus rates were increased on this soil there was a slight reduction in the quantity of material produced. The statistical analysis of the vegetative yields from the Kirkland soil, given in Table 9, indicated significant differences in the levels of reaction, levels of phosphorus and reaction-phosphorus interactions. Adjustment of the reaction of the Kirkland soil gave an overall decrease in amount of growth obtained. However, 40 pounds of P_2O_5 plus the pH adjustment produced larger yields than any other treatment. Higher levels of added phosphorus increased vegetative yields with the exception of the 40 pound per acre rate of phosphorus on the unadjusted Kirkland soil. Results from the Kirkland soil were similar to those obtained by Scarseth (33).

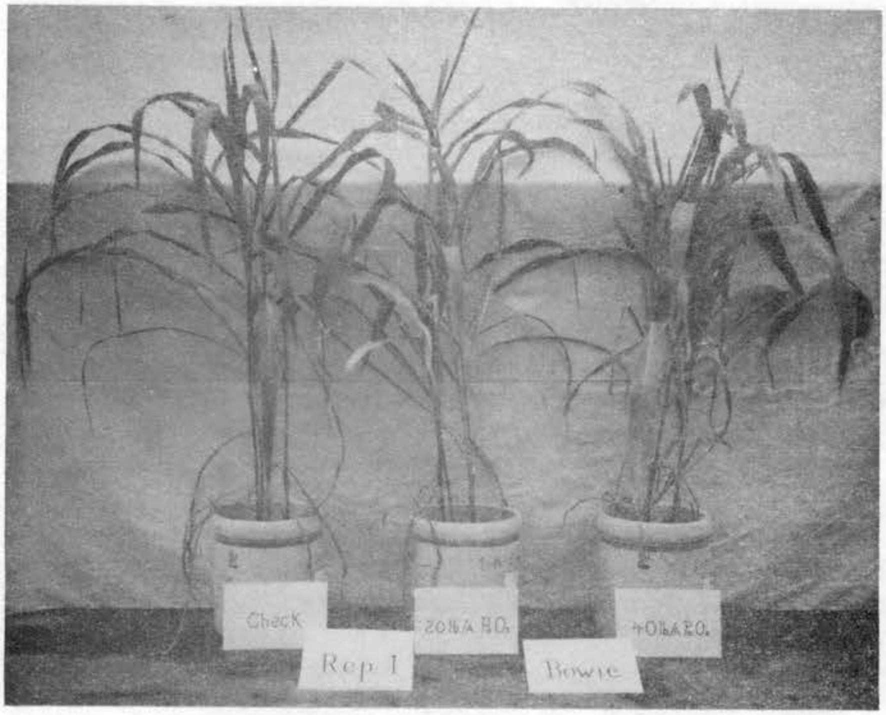

Fig. 1. Growth of corn, 58 days after planting, on an unlimed Bowie soil receiving different levels of phosphorus fertilizers.

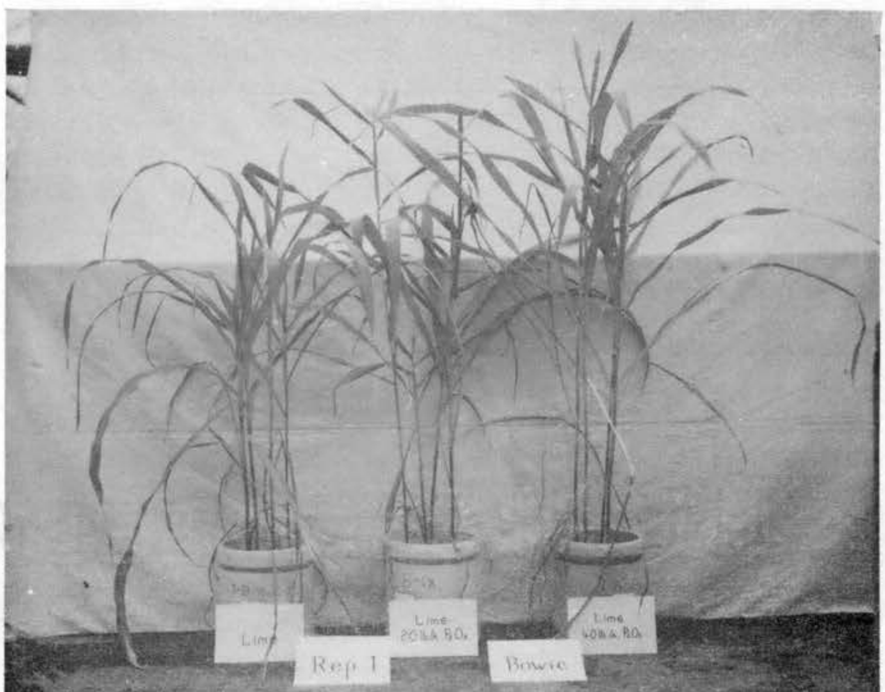

Fig. 2. Growth of corn, 58 days after planting, on a limed Bowie soil receiving different levels of phosphorus fertilizers.

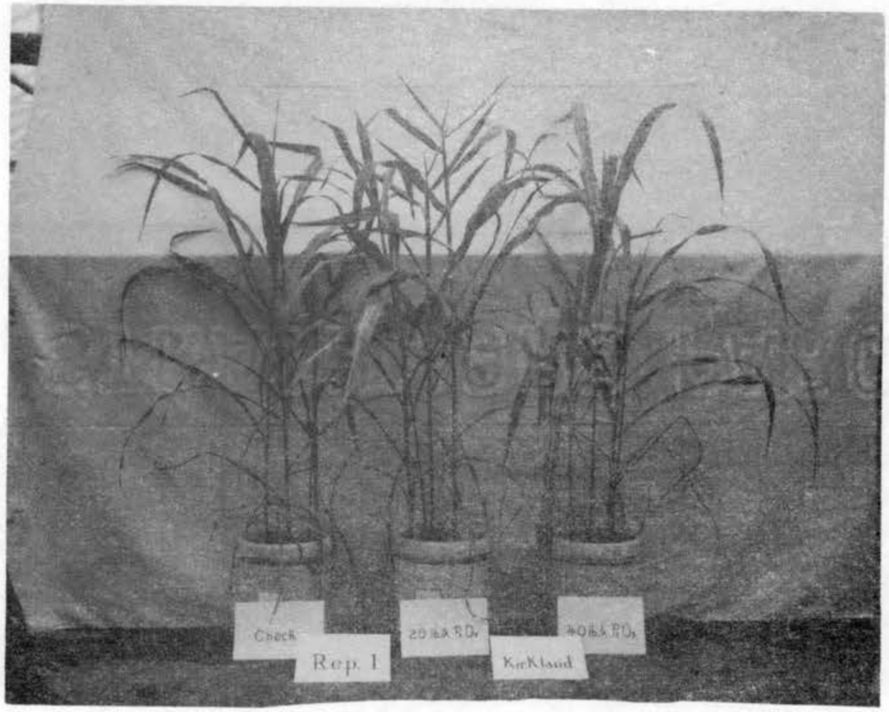

Fig. 3. Growth of corn, 58 days after planting, on an unlimed Kirkland soil receiving different levels of phosphorus fertilizers.

Fig. 4. Growth of corn, 58 days after planting, on a limed Kirkland soil receiving different levels of phosphorus fertilizers.

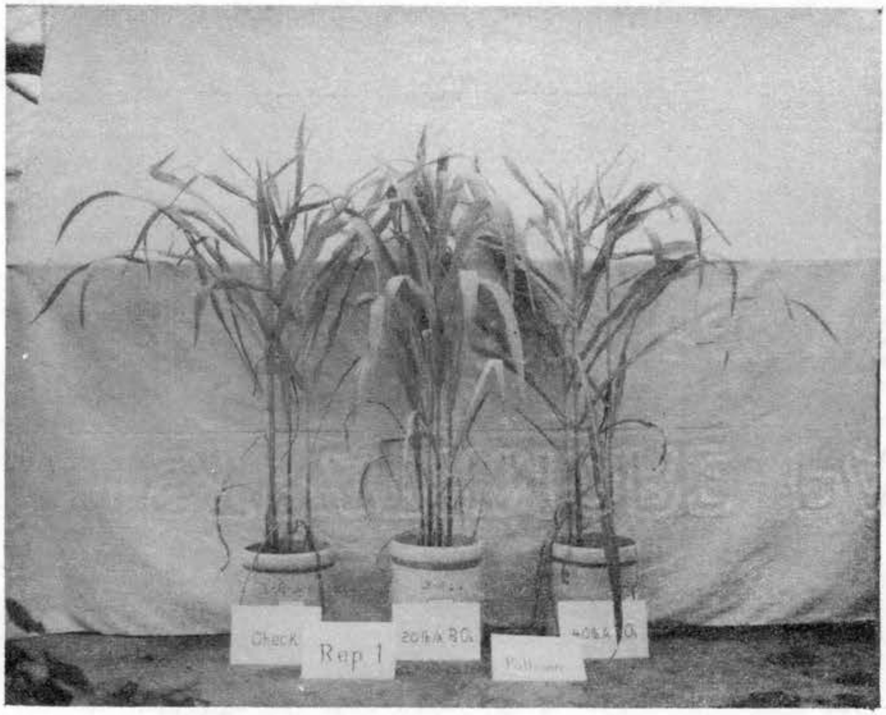

Fig. 5. Growth of corn, 58 days after planting, on an unleached Pullman soil receiving different levels of phosphorus fertilizers.

Fig. 6. Growth of corn, 58 days after planting, on a leached Pullman soil receiving different levels of phosphorus fertilizers.

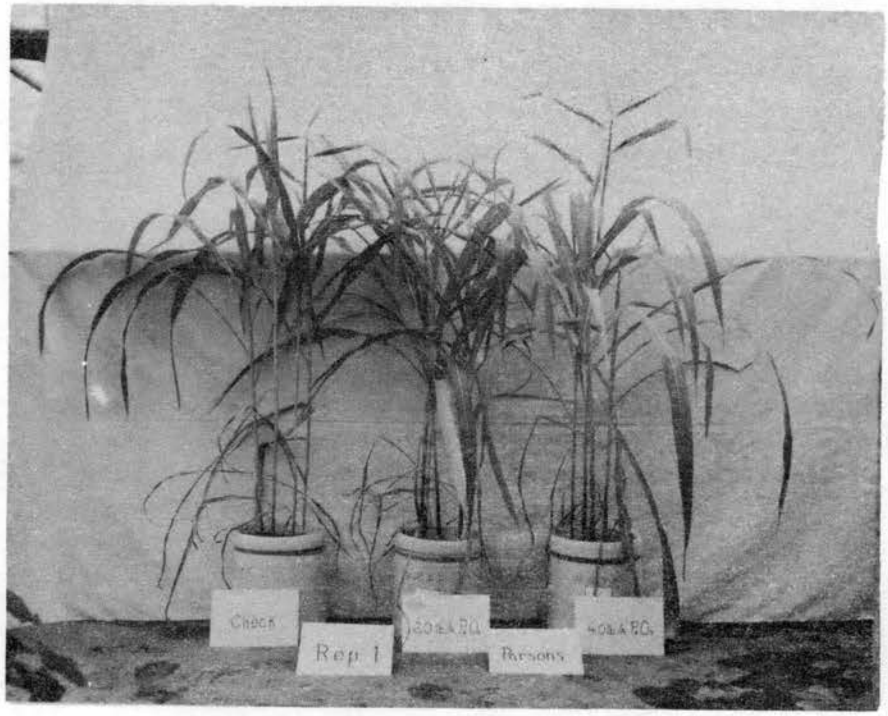

Fig. 7. Growth of corn, 58 days after planting, on an unlimed Parsons soil receiving different levels of phosphorus fertilizers.

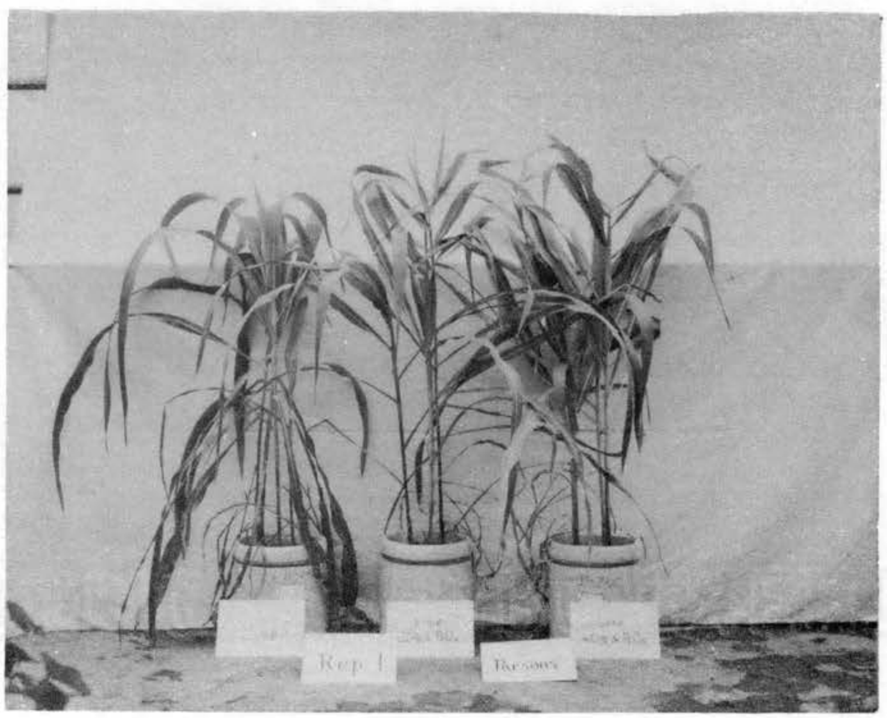

Fig. 8. Growth of corn, 58 days after planting, on a limed Parsons soil receiving different levels of phosphorus fertilizers.

Table 7. Vegetative yields of corn, expressed in grams per pot, grown on four soils in a greenhouse study.

Treatments	Soils			
	Bowie	Kirkland	Pullman	Parsons
P_0	23.17*	15.53	37.53	24.13
P_1	20.77	25.30	32.97	27.23
P_2	23.96	23.03	28.87	26.93
A P_0	20.67	7.70	33.27	25.70
A P_1	20.27	17.50	32.87	25.57
A P_2	24.70	26.30	30.43	29.03

*Average of three replications.

Key to Treatments

P_0 = 0 pounds P_2O_5 per acre

P_1 = 20 pounds P 0 per acre

P_2 = 40 pounds P_2O_5 per acre

A = Adjusted soil reaction

Table 8. Analysis of variance of the vegetative yields of corn grown on the Bowie soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	200.26	
Blocks	2	3.95	1.97
Treatments			
Level of reaction	1	2.56	2.56
Level of phos.	2	44.73	22.37
Reaction x phos.	2	8.00	4.00
Error	10	141.02	14.10

Table 9. Analysis of variance of the vegetative yields of corn grown on the Kirkland soil.

Source of variation	d.f.	S.S.	M. S.
Total	17	793.36	
Blocks	2	2.91	1.46
Treatments			
Level of reaction	1	76.47	76.47**
Level of phos.	2	553.38	276.69**
Reaction x phos.	2	122.84	61.42**
Error	10	57.76	3.78

**Indicates significance at the one percent level of confidence.

Table 10. Analysis of variance of the vegetative yields of corn grown on the Pullman soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	347.46	
Blocks	2	53.79	26.89
Treatments			
Level of reaction	1	3.92	3.92
Level of phos.	2	99.80	49.90
Reaction x phos.	2	27.08	13.54
Error	10	141.02	14.10

Table 11. Analysis of variance of the vegetative yields of corn grown on the Parsons soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	282.44	
Blocks	2	17.76	8.88
Treatments			
Level of reaction	1	2.00	2.00
Level of phos.	2	28.22	14.11
Reaction x phos.	2	12.47	6.24
Error	10	221.99	22.20

The chemical analyses of the vegetative material for phosphorus are reported in Table 12 and the analysis of variance for each soil is found in Tables 13, 14, 15 and 16. Differences in percentages of phosphorus of the plants obtained from various treatments of the Bowie and Kirkland soils were not significant. However, there did appear to be some noticeable trends. On the Bowie soil, the phosphorus percentages in the plants increased when 20 pounds of P_2O_5 were applied. No appreciable change occurred when the 40 pound rate was compared to the 20. The lime alone treatment showed a very slight increase in percentages of phosphorus of the corn over the check pots. The phosphorus percentages of the plants were reduced when lime plus phosphorus treatments were compared to additions of phosphate alone. The corn plants grown on the Kirkland soil had a reduction in percentages of phosphorus with increased rates of application and no apparent difference due to soil reactions. Vegetation obtained from the Pullman soil showed an increase in phosphorus percentages when the 40 pound rate of P_2O_5 was used and a considerable increase as a result of the adjustment of the reaction. These results were significant. Plant material harvested from the Parsons soil was highest in percentages of phosphorus on the check treatments. Adjustment of the pH produced a decrease in the phosphorus percentages which was statistically significant.

Table 12. Percentages of phosphorus in the vegetative material of corn plants grown on four soils in the greenhouse.

Treatments	Soils			
	Bowie	Kirkland	Pullman	Parsons
P_0	0.102*	0.084	0.114	0.125
P_1	0.133	0.069	0.112	0.103
P_2	0.138	0.066	0.141	0.101
A P_0	0.105	0.085	0.150	0.078
A P_1	0.117	0.072	0.150	0.076
A P_2	0.117	0.073	0.178	0.086

*Average of three replications.

Key to Treatments

P_0 - 0 pounds P_2O_5 per acre

P_1 - 20 pounds P_2O_5 per acre

P_2 - 40 pounds P_2O_5 per acre

A - Adjusted soil reaction

Table 13. Analysis of variance of phosphorus percentages in vegetative material of corn grown on the Bowie soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	0.006912	
Blocks	2	0.001212	0.000606
Treatments			
Level of reaction	1	0.000567	0.000567
Level of phos.	2	0.002017	0.001009
Reaction x phos.	2	0.000476	0.000238
Error	10	0.002640	0.000264

Table 14. Analysis of variance of phosphorus percentages in vegetative material of corn grown on the Kirkland soil.

Source of variation	d.f.	S. S	M. S.
Total	17	0.002599	
Blocks	2	0.000510	0.000255
Treatments			
Level of reaction	1	0.000057	0.000057
Level of phos.	2	0.000823	0.000412
Reaction x phos.	2	0.000446	0.000223
Error	10	0.001174	0.000117

Table 15. Analysis of variance of phosphorus percentages in vegetative material of corn grown on the Pullman soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	0.012526	
Blocks	2	0.000770	0.000385
Treatments			
Level of reaction	1	0.006086	0.006086**
Level of phos.	2	0.003199	0.001600*
Reaction x phos.	2	0.000004	0.000002
Error	10	0.002467	0.000247

**Indicates significance at the one percent level of confidence.
*Indicates significance at the five percent level of confidence.

Table 16. Analysis of variance of phosphorus percentages in vegetative material grown on the Parsons soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	0.008850	
Blocks	2	0.001237	0.000619
Treatments			
Levels of reaction	1	0.003931	0.003931**
Level of phos.	2	0.000457	0.000228
Reaction x phos.	2	0.000799	0.000399
Error	10	0.002426	0.000243

**Indicates significance at the one percent level of confidence.

With the exception of the vegetation grown on the Pullman soil, the results of the nitrogen analyses, reported in Table 17, indicated a decrease in nitrogen percentages of the plants with increased rates of applied phosphorus. Adjustment of the reaction on the Bowie, Kirkland, and Parsons soils gave an increase in percentages of nitrogen in the corn. Statistically significant differences were obtained only for the level of reaction on the Bowie soil and for level of reaction and phosphorus levels on the Kirkland soil. (Tables 18 and 19). The plant material obtained from the Pullman soil showed a slight increase in nitrogen percentages with higher rates of added phosphorus except for the 20 pound rate.

Results of the three extraction methods for available soil phosphorus are shown graphically in figures 9, 10, 11, and 12. They generally showed an increase in available phosphorus as a result of adjusting the soil reaction and also with increased rates of phosphorus applications. The smallest amount of available phosphorus was found on the Bowie soil which received twenty pounds of P_2O_5 per acre and had the reaction adjusted. Very close agreement was found on the Pullman soil between the $NaHCO_3$

Table 17. Nitrogen percentages in the vegetative material of corn grown on four soils in a greenhouse study.

Treatments	Soils			
	Bowie	Kirkland	Pullman	Parsons
P_0	0.93*	1.35	0.82	1.23
P_1	0.97	0.95	0.79	0.97
P_2	0.89	0.84	0.91	1.01
A P_0	1.04	1.75	0.80	1.29
A P_1	1.06	1.21	0.83	1.18
A P_2	0.82	1.02	0.89	1.16

*Average of three replications.

Key to Treatments

P_0 - 0 pounds P_2O_5 per acre

P_1 - 20 pounds P_2O_5 per acre

P_2 - 40 pounds P_2O_5 per acre

A - Adjusted soil reactions

Table 18. Analysis of variance of nitrogen percentages of corn plants grown on a Bowie soil.

Source of variation	d.f	S. S.	M. S.
Total	17	0.2698	
Blocks	2	0.0325	0.0163
Treatments			
Level of reaction	1	0.0086	0.0086
Level of phos.	2	0.0893	0.0447*
Reaction x phos.	2	0.0308	0.0154
Error	10	0.1086	0.0109

*Significant at the five percent level of confidence.

Table 19. Analysis of variance of nitrogen percentages of corn plants grown on a Kirkland soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	1.7276	
Blocks	2	0.0060	0.0030
Treatments			
Level of reaction	1	0.3488	0.3488**
Level of phos.	2	1.2669	0.6335**
Reaction of phos.	2	0.0347	0.0174
Error	10	0.0712	0.0071

**Significant at the one percent level of confidence.

Table 20. Analysis of variance of nitrogen percentages of corn plants grown on a Pullman soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	0.1112	
Blocks	2	0.0024	0.0012
Treatments			
Level of reaction	1	0.0000	0.0000
Level of phos.	2	0.0322	0.0161
Reaction x phos.	2	0.0038	0.0019
Error	10	0.0728	0.0073

Table 21. Analysis of variance of nitrogen percentages of corn plants grown on a Parsons soil.

Source of variation	d.f.	S. S.	M. S.
Total	17	0.6588	
Blocks	2	0.0213	0.0106
Treatments			
Level of reaction	1	0.0871	0.0871
Level of phos.	2	0.1373	0.0687
Reaction x phos	2	0.0172	0.0086
Error	10	0.3959	0.0396

and the HCL plus NH_4F extractions. On this soil the acetic acid leaching gave extremely high results, which indicated that this method removed much more phosphorus than was available for plant utilization.

Correlation coefficients among the three methods are reported in Table 22. The highest correlation was found between the $NaHCO_3$ and HCl plus NH_4F extractions while the poorest occurred between the $NaHCO_3$ and $HC_2H_3O_2$ methods. All the coefficients were significant at the one percent level of confidence.

Table 22. Correlation coefficients of three chemical methods of removing available phosphorus from soils.

Key

X_1 - 0.5 M. $NaHCO_3$ Extraction
X_2 - 0.025 N. HCL plus 0.03 N. NH_4F
X_3 - 0.10 N. $HC_2H_3O_2$ Leaching

Methods correlated	Correlation coefficient
r_{12}	0.971**
r_{13}	0.943**
r_{23}	0.956**

**Significant at the one percent level of confidence.

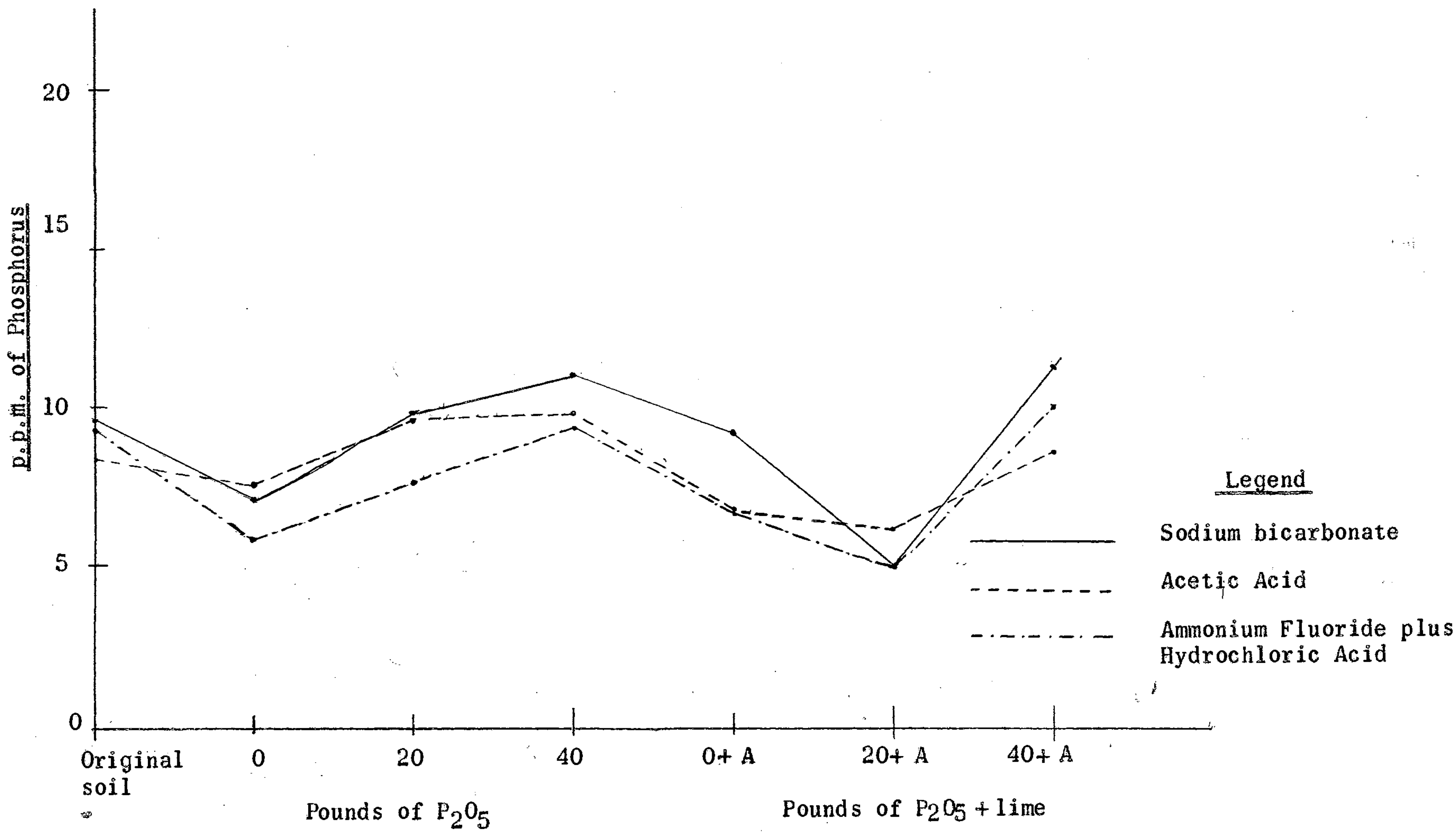

Figure 9. A comparison of three chemical methods of phosphorus extraction from a Bowie Sandy Loam.

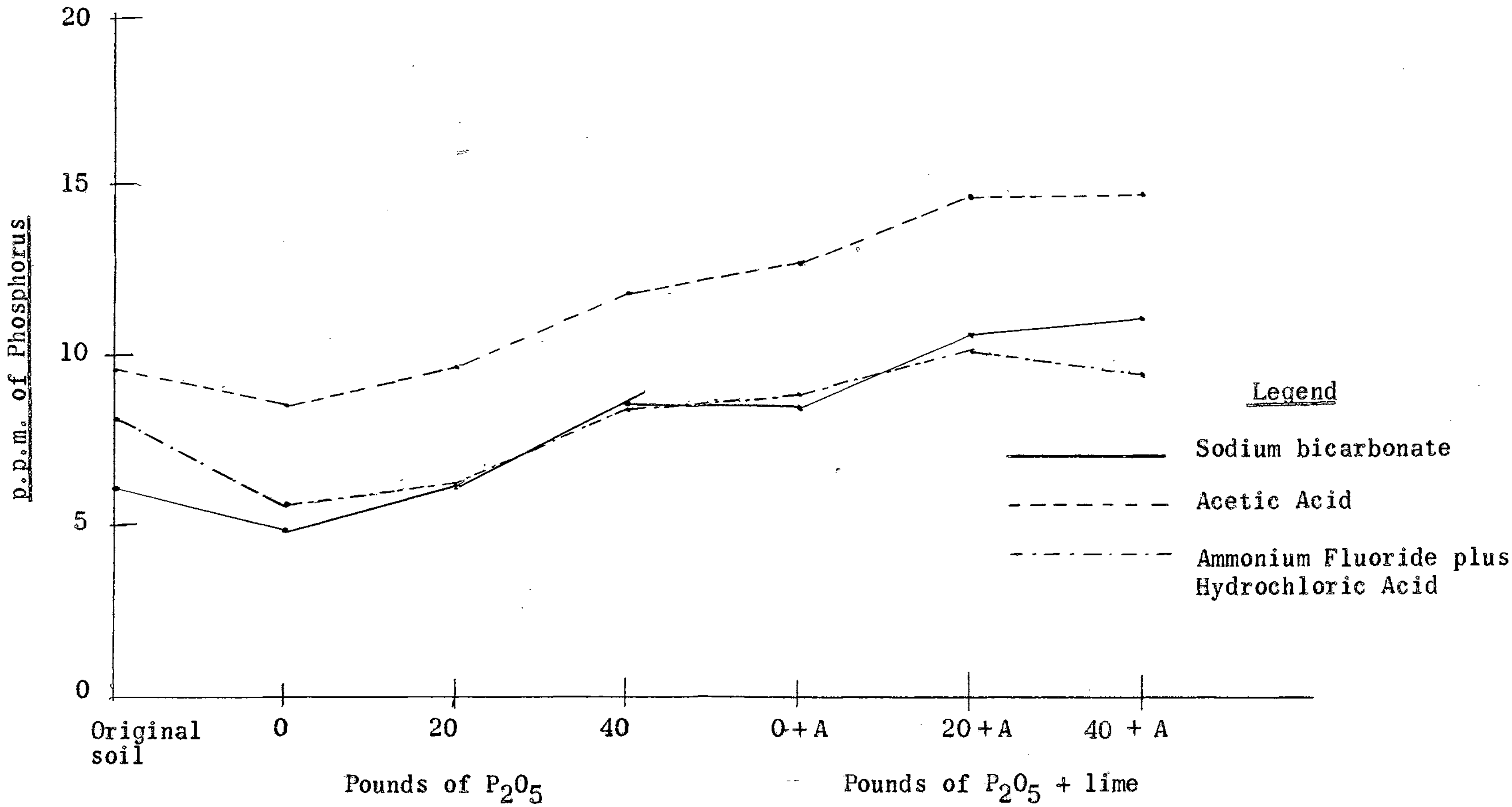

Figure 10. A comparison of three chemical methods of phosphorus extraction from a Kirkland Silt Loam

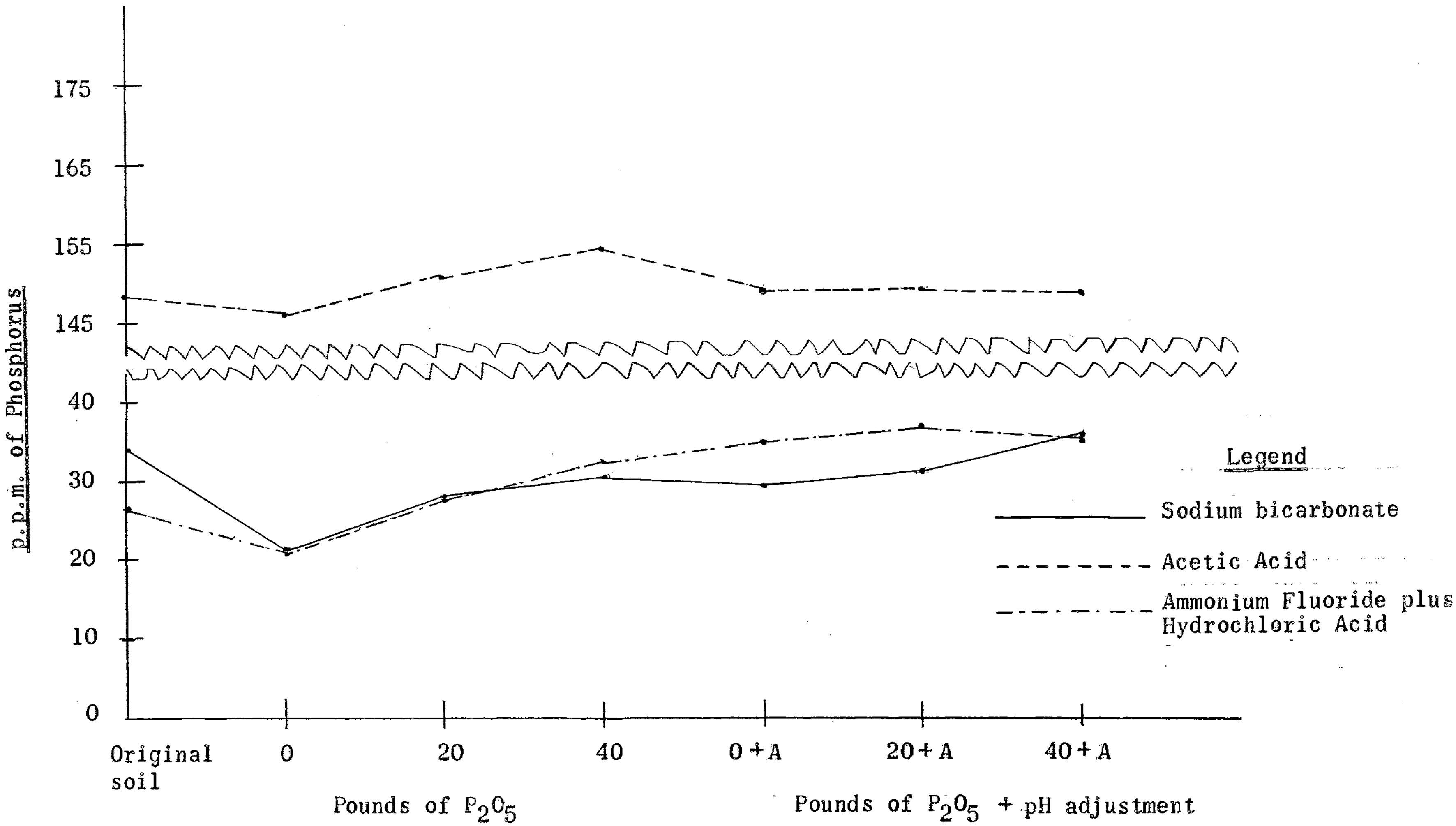

Figure 11. A comparison of three chemical methods of phosphorus extraction from a Pullman Clay Loam.

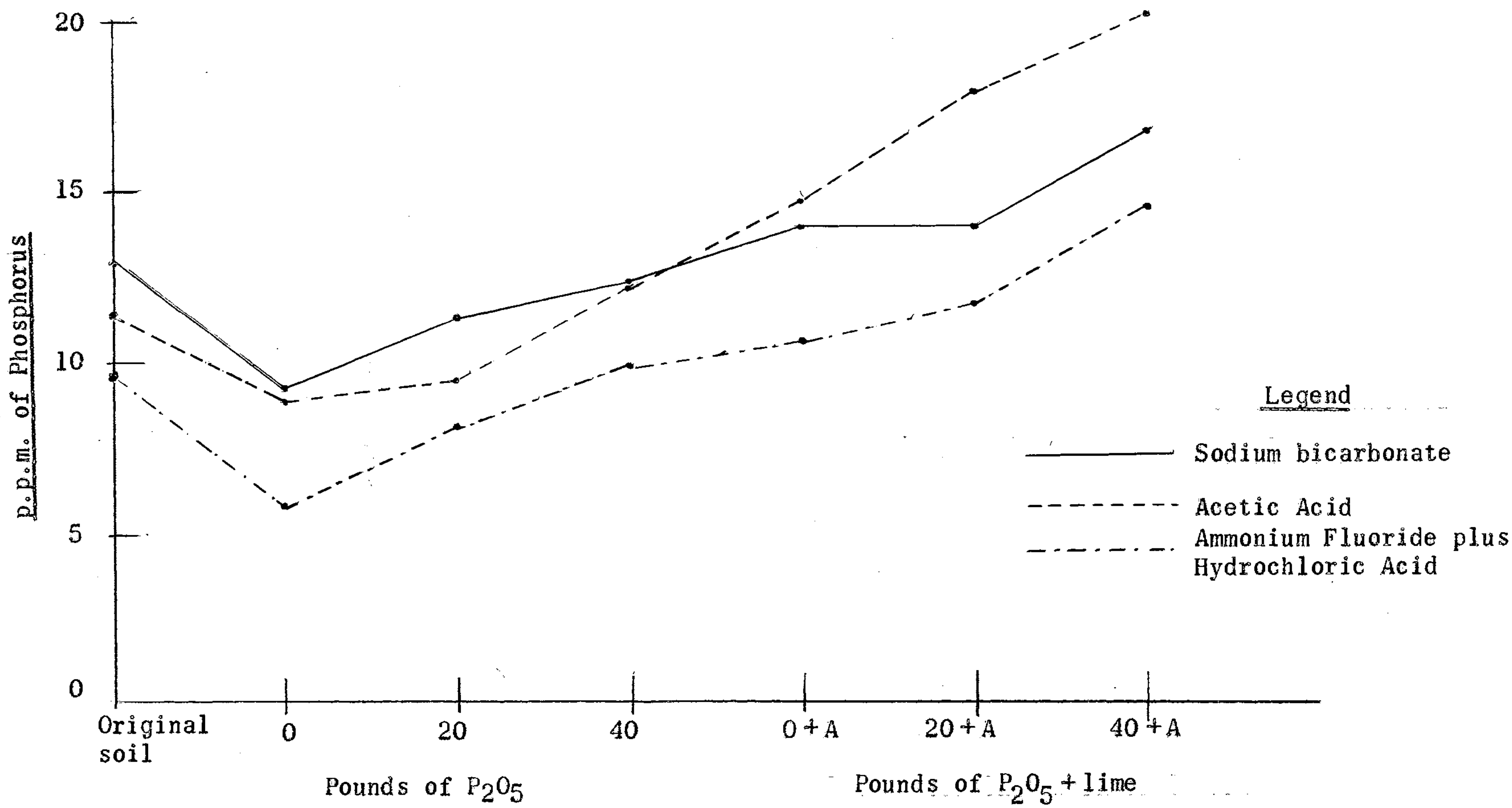

Figure 12. A comparison of three chemical methods of phosphorus extraction from a Parsons Silt Loam.

The results of the extractable iron determination, given in figure 13, indicated a considerable reduction in iron as a result of adjusting the soil reaction. The soil highest in extractable iron was the unlimed Parsons soil. Leaching had no appreciable effect on the amount of extractable iron found in the Pullman soil. The initial iron content of this soil was extremely low because of the high pH value. As the extractable iron concentration decreased, due to pH adjustment, the amount of available phosphorus increased.

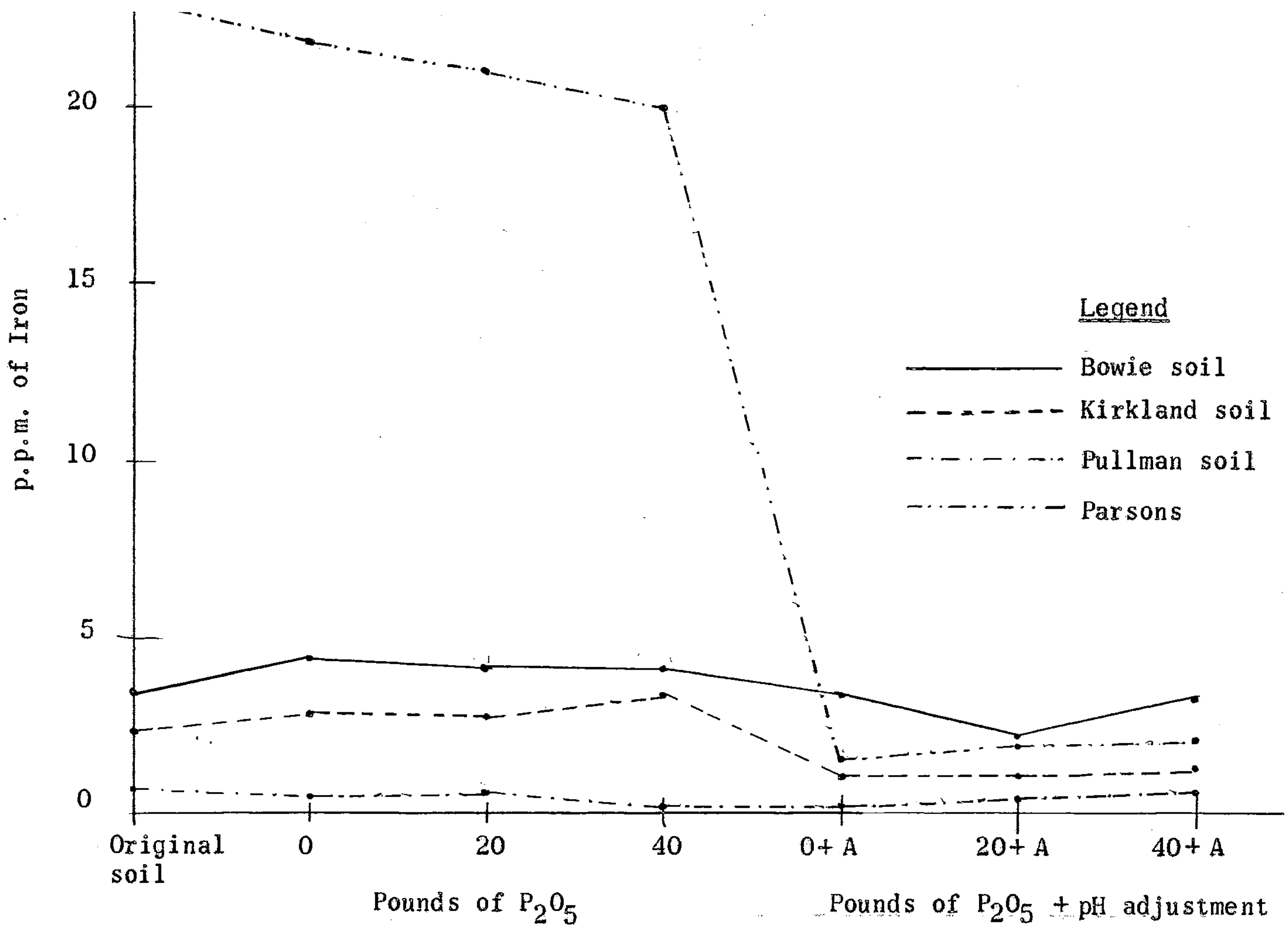

Figure 13. The relationship between extractable iron and soil reactions on four Oklahoma soils.

CHAPTER V

SUMMARY AND CONCLUSIONS

The phosphorus availability of four Oklahoma soils was studied under greenhouse conditions. The soils employed in the experiment were classified as Pullman Clay Loam, Bowie Sandy Loam, Parsons Silt Loam and Kirkland Silt Loam. The soils had adjusted and unadjusted reactions plus different levels of applied phosphorus. The three rates of phosphate used were none, 20 and 40 pounds of P_2O_5 per acre. Treatments were made in all possible combinations which gave a complete factorial design. Corn was then grown as the test crop. From the results of these experiments, the following conclusions seem justifiable:

1. The height of the plants, except those grown on the Pullman soil, indicated an early response to the added phosphorus. The reaction levels produced no noticeable differences in plant height.
2. Later, height measurements became somewhat eratic. However, the corn grown on the Kirkland soil established a trend which continued throughout the experiment.
3. The highest vegetative yields for a given soil were obtained when 40 pounds of phosphate were applied to the limed Bowie, Kirkland and Parsons soils. Increased increments of applied phosphorus depressed the amount of vegetation produced on the Pullman soil. Similar effects have been found on soils having a sufficient supply of available phosphorus.
4. The phosphorus percentages of the corn plants gave no definite trends applicable to all the soils studied. Plant material

obtained from the Pullman soil showed a definite increase in percentage of phosphorus when the heaviest rate of phosphorus was applied and the soil reaction was adjusted.

5. The corn grown on the Bowie, Kirkland and Parsons soils gave similar results when the plants were analyzed for nitrogen. The nitrogen percentages tended to decrease with higher rates of added phosphate. In direct contrast, the adjustment of pH increased the percentages of nitrogen in the plants. The vegetation obtained from the Pullman soil increased slightly in percentage of nitrogen when phosphorus was applied to the soil. No appreciable differences in nitrogen percentages occurred when the reaction of this soil was adjusted.

6. The chemical analyses of all the soils studied showed an increase in the amount of available phosphorus when rates of applied phosphate were increased and with the adjustment of the soil reaction.

7. The highest correlation between soil phosphorus extraction methods was obtained from the $NaHCO_3$ and HCl plus NH_4F extractants. The poorest correlation occurred between the $NaHCO_3$ and $HC_2H_3O_2$ methods.

8. The amount of extractable iron in the soils, except the Pullman soil, decreased when the pH value was adjusted. The Pullman soil had a very low initial concentration of extractable iron. The amount of available phosphorus in the soils increased when the extractable iron content decreased.

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APPENDIX

Table 23. Results of first height measurement of corn, 20 days after planting.

Soil and Treatment		Replication I	II	III
Bowie	P_o	24.06*	24.25	26.06
	P_1	25.44	28.25	28.94
	P_2	28.94	26.56	29.50
	A P_o	22.50	23.00	24.19
	A P_1	28.63	27.06	26.25
	A P_2	30.75	27.06	27.63
Kirkland				
	P_o	20.50	22.00	21.69
	P_1	25.81	26.13	24.38
	P_2	25.00	26.25	28.00
	A P_o	20.06	18.25	23.31
	A P_1	20.81	22.38	23.63
	A P_2	24.13	26.00	28.86
Pullman				
	P_o	26.06	24.63	33.94
	P_1	25.69	28.06	25.86
	P_2	25.56	26.19	23.25
	A P_o	28.63	27.88	28.06
	A P_1	27.56	25.56	29.06
	A P_2	27.38	28.06	23.00
Parsons				
	P_o	20.19	18.19	20.75
	P_1	25.38	24.63	24.56
	P_2	25.63	27.75	23.88
	A P_o	19.88	21.56	25.44
	A P_1	23.56	24.56	26.69
	A P_2	26.44	23.19	25.50

*Represents an average of four plants per pot expressed in inches.

Key to Treatments

P_o - 0 P_2O_5 per acre

P_1 - 20 pounds P_2O_5

P_2 - 40 pounds P_2O_5 per acre

A - Adjusted soil reaction

Table 24. Results of second height measurement of corn, 44 days after planting.

Soil and Treatment		Replication I	II	III
Bowie				
	P_0	50.63*	51.81	55.69
	P_1	43.50	47.75	46.75
	P_2	44.38	41.62	43.50
	A P_0	45.38	50.25	49.13
	A P_1	48.88	44.50	47.13
	A P_2	54.13	42.75	42.38
Kirkland				
	P_0	45.00	45.19	43.31
	P_1	47.38	47.25	43.13
	P_2	43.50	41.75	43.88
	A P_0	37.75	35.13	34.88
	A P_1	51.00	48.25	42.06
	A P_2	47.75	54.19	46.50
Pullman	P_0	49.19	50.00	49.50
	P_1	44.69	48.06	49.25
	P_2	46.63	47.88	42.31
	A P_0	48.38	45.50	46.88
	A P_1	44.63	46.00	45.25
	A P_2	50.25	48.31	42.88
Parsons				
	P_0	51.00	44.44	51.00
	P_1	46.88	46.00	44.75
	P_2	50.25	50.00	37.38
	A P_0	48.88	48.88	49.13
	A P_1	50.38	49.38	54.06
	A P_2	49.75	50.88	48.94

*Represents an average of four plants per pot expressed in inches.

Key to Treatments

P_0 = 0 P_2O_5 per acre
P_1 = 20 pounds P_2O_5
P_2 = 40 pounds P_2O_5 per acre
A = Adjusted soil reaction

Table 25. Results of vegetative yields of corn

Soil and Treatment	Replication I	II	III
Bowie			
P_0	20.4*	22.7	26.4
P_1	17.6	22.5	22.2
P_2	23.2	20.0	28.7
A P_0	21.7	21.8	18.5
A P_1	18.4	20.4	22.0
A P_2	30.5	23.9	19.7
Kirkland			
P_0	15.4	16.1	15.1
P_1	27.6	24.5	23.8
P_2	21.1	22.7	25.3
A P_0	8.2	7.0	7.9
A P_1	17.8	16.9	17.8
A P_2	28.2	28.2	22.5
Pullman			
P_0	30.7	35.5	46.4
P_1	30.0	37.7	31.2
P_2	27.2	32.9	26.5
A P_0	33.0	32.9	33.9
A P_1	32.4	29.9	36.3
A P_2	28.3	31.5	31.5
Parsons			
P_0	22.9	27.6	21.9
P_1	30.4	25.3	26.0
P_2	32.6	25.8	22.4
A P_0	22.6	25.6	28.9
A P_1	21.8	22.2	32.7
A P_2	34.6	24.1	28.4

*Represents total weight of plant material from each pot. Expressed in grams.

Key to Treatments

P_0 = 0 P_2O_5 per acre
P_1 = 20 pounds P_2O_5
P_2 = 40 pounds P_2O_5 per acre
A = Adjusted soil reaction

Table 26. Phosphorus percentages of corn in vegetative growth.

Soil and Treatment	Replication I	II	III
Bowie			
P_0	0.108*	0.111	0.088
P_1	0.151	0.124	0.123
P_2	0.157	0.157	0.100
A P_0	0.096	0.114	0.106
A P_1	0.120	0.110	0.121
A P_2	0.137	0.103	0.111
Kirkland			
P_0	0.086	0.086	0.080
P_1	0.070	0.077	0.060
P_2	0.067	0.062	0.069
A P_0	0.077	0.100	0.077
A P_1	0.082	0.069	0.064
A P	0.056	0.098	0.066
Pullman			
P_0	0.121	0.119	0.103
P_1	0.103	0.124	0.108
P_2	0.168	0.114	0.142
A P_0	0.155	0.156	0.139
A P_1	0.150	0.173	0.126
A P_2	0.182	0.180	0.172
Parsons			
P_0	0.138	0.110	0.128
P_1	0.118	0.098	0.094
P_2	0.106	0.116	0.080
A P_0	0.095	0.074	0.066
A P_1	0.102	0.062	0.065
A P	0.081	0.069	0.108

*Expressed as percent.

Key to Treatments

P_0 - 0 P_2O_5 per acre
P_1 - 20 pounds P_2O_5
P_2 - 40 pounds P_2O_5 per acre
A - Adjusted soil reaction

Table 27. Nitrogen percentages in corn plants.

Soil and Treatments	Replication I	Replication II	Replication III
Bowie			
P_o	1.03*	1.00	0.75
P_1	1.08	0.90	0.92
P_2	0.92	0.96	0.80
A P_o	0.92	1.05	1.17
A P_1	1.11	1.03	1.03
A P_2	0.94	0.80	0.71
Kirkland			
P_o	1.42	1.35	1.29
P_1	0.94	1.01	0.91
P_2	0.90	0.86	0.75
A P_o	1.77	1.63	1.85
A P_1	1.26	1.26	1.10
A P_2	0.95	1.02	1.08
Pullman			
P_o	0.84	0.86	0.76
P_1	0.75	0.81	0.81
P_2	1.03	0.74	0.97
A P_o	0.78	0.81	0.82
A P_1	0.83	0.91	0.75
A P_2	0.90	0.83	0.93
Parsons			
P_o	1.34	0.98	1.38
P_1	0.84	1.03	1.04
P_2	0.89	1.10	1.03
A P_o	1.55	1.31	1.01
A P_1	1.45	1.10	0.99
A P_2	1.05	1.21	1.20

*Expressed as percent.

Key to Treatments

P_o - 0 P_2O_5
P_1 - 20 pounds P_2O_5
P_2 - 40 pounds P_2O_5 per acre
A - Adjusted soil reaction

Table 28. Results of three chemical methods of phosphorus extraction.

Soils and Treatments	Extraction Method: 0.5 M. $NaHCO_3$	0.03 N. NH_4F in 0.025 N. HCl	0.1 N. $HC_2H_3O_2$
Bowie			
Original Soil	9.67*	9.35*	8.40
P_o	7.11	5.80	7.60
P_1	9.82	7.70	9.68
P_2	11.02	9.35	9.84
A P_o	9.23	6.75	6.80
A P_1	5.13	5.00	6.24
A P_2	11.33	10.10	8.64
Kirkland			
Original Soil	6.09	8.10	9.52
P_o	4.87	5.60	8.40
P_1	6.09	6.15	9.60
P_2	8.49	8.40	11.76
A P_o	8.34	8.75	12.56
A P_1	10.57	10.10	14.56
A P_2	11.03	9.35	14.64
Pullman			
Original Soil	34.02	26.60	148.40
P_o	21.36	21.05	146.00
P_1	28.16	27.75	150.80
P_2	31.26	32.05	154.00
A P_o	29.04	34.50	148.80
A P_1	31.72	36.25	148.80
A P_2	36.28	35.10	148.40
Parsons			
Original Soil	12.83	9.65	11.36
P_o	9.09	5.75	8.88
P_1	11.19	8.10	9.44
P_2	12.24	9.80	11.92
A P_o	13.88	10.50	14.56
A P_1	13.57	11.60	17.76
A P_2	16.64	14.35	20.00

*Expressed as parts per million.

Key to Treatments

P_o - 0 pounds P_2O_5 per acre
P_1 - 20 pounds P_2O_5 per acre
P_2 - 40 pounds P_2O_5 per acre
A - Adjusted soil reaction

Table 29. Results of extractable iron determination.

Treatments	Soils			
	Bowie	Kirkland	Pullman	Parsons
P_0	4.35	2.85	0.50	21.80
P_1	4.15	2.75	0.60	21.00
P_2	4.15	3.35	0.20	20.15
A P_0	3.45	1.10	0.20	1.60
A P_1	2.25	1.10	0.45	1.90
A P_2	3.35	1.25	0.60	2.10
Original soil	3.45	2.35	0.75	23.10

*Expressed as parts per million.

Key to Treatments

P_0 - 0 pounds P_2O_5 per acre
P_1 - 20 pounds P_2O_5 per acre
P_2 - 40 pounds P_2O_5 per acre
A - Adjusted soil reaction

Table 30. pH of soil samples taken from pot cultures.

Treatments	Soils			
	Bowie	Kirkland	Pullman	Parsons
P_0	4.7	5.1	6.7	4.7
P_1	4.9	5.1	6.8	4.7
P_2	4.9	5.1	6.7	4.7
A P_0	5.2	6.4	6.4	6.9
A P_1	5.5	6.7	6.3	7.0
A P_2	5.2	6.8	6.3	6.8

Key to Treatments

P_0 - 0 pounds P_2O_5 per acre
P_1 - 20 pounds P_2O_5 per acre
P_2 - 40 pounds P_2O_5 per acre
A - Adjusted soil reaction

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