A COMPARISON OF DIFFERENT METHODS FOR DETERMINING AVAILABLE PHOSPHORUS IN SOILS AND THE CORRELATION OF THESE TESTS WITH CROP YIELDS

By

ROBERT ARTHUR OPPEL

Bachelor of Science
Oklahoma Agricultural and Mechanical College
Stillwater, Oklahoma
1952

Submitted to the faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1957

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Thesis Approved:

Robert M. Reed
Thesis Adviser

J. Q. Lynd

Robert MacVicar
Dean of the Graduate School

ACKNOWLEDGEMENT

The writer wishes to express his appreciation to the staff of the Agronomy Department of Oklahoma Agricultural and Mechanical College for their helpful advice and criticisms and especially to Dr. Robert M. Reed, under whose supervision the experimental work was carried out. Dr. Robert M. Reed has been a constant source of encouragement and guidance and has offered invaluable constructive criticisms in the writing of this thesis.

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I. INTRODUCTION

Phosphorus has been called the master key to agriculture. Low crop production is caused more often by a lack of phosphorus than a deficiency of any other nutrient. Some of the many functions of phosphorus within plants are as follows: stimulates early root formation and growth; gives rapid and vigorous start to plants; hastens maturity of crops; especially important in seed formation; and increases the ratio of grain and fruit to stalk. The phosphorus content of soils differs greatly. The total amount which will ordinarily be found in mineral soils ranges from 0.02% to 0.40 %. Inorganic and organic forms of phosphorus occur in soils and both are important to plants as a source of this element.

Soil tests for available phosphorus by the use of various extractants and different procedures have been investigated during the past thirty years. However, a test has not as yet been devised, which can be employed successfully on all kinds of soil. The measurement of available phosphorus in soils is very difficult because the forms of phosphorus vary in their solubility and degree of fixation. However, some tests have given promising results on both alkaline calcareous and acid soils.

According to Olsen _et_ _al_., (29)[1] a soil test which successfully determines the available phosphorus in a soil must fulfill the following

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[1] Figures in parenthesis refer to "Literature Cited."

requirements:

(a) It must extract all or a definite proportion of the various forms of soil phosphorus in the same relative amounts as they are absorbed by plants.

(b) It must measure with reasonable accuracy the amount of phosphorus in the extract.

(c) It must correlate fairly closely with the amount of phosphorus taken up by plants and the yield responses to added phosphorus over a wide range of soils.

(d) It must minimize secondary precipitation and adsorption reactions which may occur during the reaction.

(e) It must be fairly rapid in its action.

The objectives of this study were twofold: First, the correlation of chemical methods of testing soils for available P with growth responses obtained in fertilized greenhouse pot studies; secondly, the relationship of yield responses in field experimental fertilizer trials with laboratory "quick" soil tests for available phosphorus. On the soils analyzed, the method which tended to give the best agreement with crop response would be the most applicable.

II. REVIEW OF LITERATURE

Extraction Procedures

Hockensmith et al. (22) stated that the weak acid digestion methods of extraction tended to correlate very well with field results in the acid-humid region; however, disappointing results were obtained from tests run on calcareous soils in the semi-arid west. Acid extractions removed a large amount of soluble phosphorus if the pH of the soil was low; whereas, on soils which had a high pH, the amount of phosphorus dissolved was usually small. He concluded that on alkaline calcareous soils, an alkaline solvent appeared to be more satisfactory than an acid extractant.

Extraction of soluble phosphorus comparable with the amount absorbed by plants was attempted by Truog (37). This method employed .002 N sulfuric acid buffered to a pH of 3.0 with ammonium sulphate and a shaking period of 30 minutes. He distinguished between readily available and difficultly available soil phosphorus. He stated that there are actually no unavailable phosphates because some plants are able to use phosphates which may be rather difficultly available.

As a result of an extensive investigation of different chemical methods which had been proposed for the determination of the easily soluble phosphorus content of soils, Harper (20) found that the 0.1 N acetic acid method of extraction gave the best correlation between the response from phosphorus fertilizers applied to crops grown on different soils and the easily soluble phosphorus removed from the soil. However, in case of calcareous soils in which considerable amounts of occluded phosphate occurs, the method can not be recommended.

A procedure for the determination of phosphorus in the presence of arsenic was adapted for use with a sodium acetate extracting solution. (1) Data were presented for soil samples to which arsenic had been added, which showed that the proposed method was satisfactory. The use of sodium acetate solution as an extractant in a system of rapid tests for available plant food constituents in soils was first introduced by Morgan in 1935 under the designation of the "Universal soil extracting solution." Since that time, this solution has been used in soil fertility investigations by many workers in various parts of the world.

Bray and Kurtz (6) made the distinction between adsorbed and acid-soluble phosphorus. Their method involved the use of ammonium fluoride in the extracting solution to remove the adsorbed forms of phosphate and to separate them from the acid-soluble forms.

Rubins (34) compared certain methods of extracting available phosphorus on different soils in Maine. He stated that the Truog, Egner, and acetic acid methods extracted a greater amount of the phosphorus than did the Morgan method. Most of the chemical methods were fairly significant in the amount of available phosphorus they extracted, while the biological tests did not correlate very closely.

A relatively new method of extracting soil phosphorus with 0.5 molar solution of sodium bicarbonate adjusted to pH 8.5 performed well on both acid and calcareous soils. (29) This procedure gave better correlations than the Bray, water-soluble and carbon dioxide-soluble methods. This method is not as readily affected by secondary precipitation and adsorption as those involving mineral acids.

A comparison of 1% potassium carbonate and 1% citric acid as extracting agents for available phosphoric acid on different types of soils was conducted by Das (9). He found that the potassium carbonate method was equally applicable on both acid and calcareous soils. However, the citric acid method failed to give comparable results on alkali and calcareous soils.

In their studies of the relationship of pH to phosphate solubility in Colorado soils, Gardner and Kelly (15) also found that acid extractant results did not correlate very well with available phosphorus. Whereas, the phosphorus which was removed with potassium carbonate correlated closely with the available phosphorus on calcareous soils. However, on non-calcareous soils the potassium carbonate extractant was undesirable because it gave false high results.

McGeorge _et al_. (27) stated that the solvent action of carbon dioxide on phosphorus in calcareous soils was mainly a function of the reaction and that the H ion activity must be sufficient to overcome the common ion effect of Ca in precipitation of a calcium phosphate. Thus, two reactions with opposite effects on phosphate solubility occur when carbon dioxide is bubbled through a calcareous soil. They are an increase in solubility caused by a decrease in pH and a decrease in solubility when precipitation of a calcium phosphate occurs as a result of the increase in Ca ion activity.

The use of electrodialysis for determining phosphate availabiltiy in calcareous soils was studied by Goodwin (18). He found that the potassium carbonate-soluble phosphorus and water-soluble phosphorus tests gave better correlation with crop growth and phosphate fertilization than the phosphorus removed by electrodialysis.

Color Development

Color development is very important in the measurement of the amount of phosphorus which has been extracted. According to Peech (31), some of the variables which affect color formation are: nature and concentration of acid employed, amount of molybdate, ratio of the molybdate to acid, and the amount of reducing agent used.

A colorimetric method of determining phosphates was described by Dickman and Bray (11), in which a molybdate-hydrochloric acid solution replaced the molybdate-sulfuric acid solution employed in the Troug and Meyer (38) method. It has the advantages of tolerating up to 15 ppm of ferric chloride in final concentration without affecting color intensity. Also less fading occurred with this procedure. Chapman (8) found that the pH of the final solution prior to color development was quite critical. When the concentration of acid with a given molybdate solution was too low, the reduction of some of the foreign constituents was permitted and a false blue color was formed. For example, under conditions of low acidity, silica may form a silico-molybdate which persisted even after the pH was decreased. A pH value below the optimum level prevented full color development of ammonium phospho-molybdate.

Different reducing agents have different requirements for optimum color development. Some of these factors affecting color development with methyl-p-amino-phenol sulphate (Elon), and 1 amino - 2 naphthol - 4 sulphonic acid were studied by Holmes and Motzok (23). They stated that with 1 amino - 2 naphthol - 4 sulphonic acid as the reducing agent the optimum time for color development was approximately 20 minutes and the suitable ranges of acidity in the final solution was from a pH of 0.5 to pH of 0.6. With Elon, the optimum time for color formation was about 30 minutes and the suitable acidity in the final solution was a pH ranging from 0.2 - 0.8. Elon gave a molybdenum blue color which was more stable than the sulphonic acid and thus seemed to be a more suitable reducing agent. They also revealed that stannous chloride was much more sensitive than either of the reducing agents just described, although what it gained in sensitivity it lost in safety, because it has a narrow range of acid tolerance and the molybdenum blue color is not stable very long after development.

The Truog and Meyer colorimetric method for the determination of phosphate was investigated by Chapman (8). He found that when the amount of stannous chloride was varied up to 0.60 mgm., the color was proportional to the amount of reducing agent used. However, larger quantities of reducing agent tended to increase the color somewhat.

Atkinson et al. (1) discovered that soils receiving arsenical sprays contained appreciable amounts of arsenic in the arsenate form. These soils gave erroneous results for available phosphorus because arsenic forms a blue color with molybdate, which is similar to the phosphorus color. However, they adapted a procedure for determining phosphorus in the presence of arsenic. Their method eliminated the arsenic interference by changing the arsenate form to an arsenite with sodium bisulfite before color development.

Ferric iron in amounts exceeding 4-6 ppm interferes with the phosphorus determination. Interference by iron was lessened when stannous chloride was placed in solution immediately after the molybdate. Only in the presence of comparatively high concentrations of nitrates, sulfates, or chlorides, was there any effect upon the accuracy of the test.

Kurtz (24) found that fluoride gave negative interferences in molybdenum blue color development; especially when phosphorus was present in small amounts. He concluded that this interference could be eliminated by either evaporating the filtrate with perchloric acid or by the addition of boric acid, prior to color formation. The boric acid forms a fluo-borate ion with fluoride ion, and thus eliminated interference by the fluoride ion. However, the procedure of Dickman and Bray (11), in which molybdate-hydrochloric acid was used instead of molybdate-sulfuric acid, was unaffected by fluoride interferences.

It has been recommended by Yien and Chesnin (39), that standards used in making calibration curves in the colorimetric determination of phosphorus in plant and soil samples, should be prepared and handled in the same manner as the unknowns. He found that the nature and concentration of ions in the extracting solution had an effect upon color development and the addition of the solvent or extracting solution to the standards and unknowns eliminated this source of error.

Correlation Studies

Correlation of the various methods of determining available phosphorus with crop yields is the only means by which a correct evaluation can be made. A method of measuring the relationship between available plant nutrients on responding and non-responding soils and chemical extractants was proposed by Fried and Dean (13). This method assumed that when two sources of a given nutrient are present in the soil the plant will absorb from each of these sources in proportion to the respective quantities available. The quantity of an available nutrient in the soil can be determined in terms of a standard, when the proportion of the nutrient in the plant derived from this standard is determined. This involved the accurate measurement of the effects of the nutrient from the standard by some means such as radio-active phosphorus.

Bray's (4) method of correlation of soil tests with crop yields used the yield from a soil which has received full treatment of all nutrients as 100% yield. Yields from those soils which have one nutrient lacking were expressed as percentage yields of the fully treated soils. The percentage yield values for different soils were then plotted against the soil test values.

Two methods of approach were used in showing the degree of correlation by Long and Seatz (25). One method was concerned with "prediction accuracy" at only the lower values of soil phosphorus or potassium. The other method involved regression curves and correlation coefficients for the experiments as a whole. The reliability of any soil test depends upon how well it can be correlated with the degree of plant response to fertilizers applied to soils of various nutrient levels.

III. MATERIALS AND METHODS

Description of Soils Used for the Greenhouse Experiments

Five bulk surface soil samples were collected in various sections of the state of Oklahoma. These soils were selected from areas in which wheat is the major crop. Greenhouse studies and laboratory tests were conducted on these soils.

A sample from the northern part of the state was obtained 4½ miles east of Renfro and 9 miles northeast of Medford, in Grant county. It was located on the southwest quarter of section 6; Township 28 N.; Range 3 W. This soil had been classified as an Oswego silt loam (17). However, at present this series name has been changed to Tabler. This soil has a gray or brownish-gray friable top soil ranging from 6 to 8 inches, grading into a friable very dark grayish-brown or black granular subsoil. It is developed on flat or gently undulating uplands, which have slow surface drainage.

In the southwestern section of the state, soil was taken 1 mile south of Frederick, in Tillman county. The legal description of this land is the southwest quarter of section 19; Township 2 S.; Range 3 W. This soil is classified as a Tillman loam (16). It has a chocolate-brown friable loam surface soil to a depth of 6 inches with a reddish-brown tough, plastic clay subsoil. The material is calcareous at a depth of 24 inches. Tillman loam is formed on smooth, gently rolling areas and has good drainage.

The soil sample from the western portion of the state was secured 8 miles east and 4 miles south of Vici in Dewey county. It was located on the northeast quarter of section 26; Township 19 N.; Range 19 W. A detail soil survey has not been made in this county, but from all indications this soil corresponds to a Weymouth sandy loam (12) which has been mapped in Woodward county. The top soil is brownish-red in color with a granular red calcareous sub-soil. This soil is found on well-drained rolling areas.

From the central part of the state, two bulk samples were obtained from Kingfisher county. One soil sample was taken from a farm located on the southeast quarter of section 27; Township 16 N.; Range 9 W., which is 12 miles west of Kingfisher. This area also has not been mapped as yet, however, it is now in the process of being mapped. According to the characteristics of the soil profile, it is similar to the Port series. (14). The top soil is reddish-brown in color with a medium subangular clayey subsoil. This series is developed on nearly level areas with relatively slow drainage. The soil occasionally floods. The other soil sample from Kingfisher county was taken 15 miles west of Kingfisher, on the northwest quarter of section 30; Township 16 N.; Range 9 W. This soil resembles the Kirkland series (14), which is formed on fairly level uplands. The top soil is dark grayish brown in color with a very slowly permeable clay subsoil.

Table I gives some of the physical and chemical characteristics of these five soils. All the soils had an ample supply of nitrogen and potassium for good plant growth. For the greenhouse experiment, acidity was corrected by the addition of calcium carbonate. The Medford soil received the equivalent of 3 tons per acre, while the equivalent of 2 tons

TABLE I

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS USED IN THE GREENHOUSE EXPERIMENT

Soil Location	Mechanical Composition[1]			Textural Class	Soil Reaction[2] (pH)	Percent Total Nitrogen[3]	Available Potassium[4] (lbs./Acre)
	% Sand	% Silt	% Clay				
Frederick	38	41	21	Loam	5.9	0.079	750
Medford	23	57	20	Silt Loam	4.9	0.084	462
Kingfisher A	43	39	18	Loam	7.0	0.083	428
Kingfisher	35	41	24	Loam	6.8	0.096	436
Vici	43	40	17	Loam	6.0	0.094	552

Each value represents the mean of two determinations.

1. Determined by method of Bouyoucos. (3)
2. Peech's method. (32)
3. Determined by method of Piper. (33)
4. Toth's method. (36)

of limestone per acre were added to the Frederick and Vici soils.

Greenhouse Procedure

Approximately 1 inch of coarse sand was placed in the bottom of 2-gallon glazed pots prior to the addition of the soils. This layer of sand would permit the removal of excess water which might accumulate in the bottom of the pots. If it was necessary, suction could be applied to a glass tube placed in the sand, to prevent water logged conditions. Equal amounts of air-dry soil from the 5 different locations were weighed out and placed on top of the sand in the pots. Each soil was then treated with an equivalent of 0, 20, and 40 pounds of P_2O_5 per acre. The treatments were replicated four times and the pots were completely randomized on the greenhouse bench. The fertilizer was applied as mono-calcium phosphate solution, approximately two inches below the surface of the soil.

On November 30, 1953, Concho wheat was planted in the pots. One dozen seeds were placed approximately 3/4 inch deep in each pot. When the seedlings were two weeks old, they were thinned to ten plants per pot. The plants were watered with distilled water when the soil appeared to be drying out on top. "Systox" was put in the water for the control of red mites. Wire hoops, made of soft telephone wire, were used to hold plants in an upright position after they reached a height of approximately 6 inches. Observations of the color, height, and percentage of dead leaves were made periodically.

On February 4, 1954, the plants were clipped to a height of 3½ inches. The plant material was oven-dried, weighed, and ground in a micro-Wiley mill equipped with a 20-mesh screen. The plant samples were then analyzed for nitrogen and phosphorus. On February 6, 1954, each pot received a surface application equivalent to 100 pounds per acre of ammonium nitrate in a liquid form. Another 100 pound addition was made on March 25, 1954. In order that jointing and stooling might occur, the plants were subjected to cold on March 29, 1954, by leaving the pots outside of the greenhouse for several days and nights. On April 25, 1954, the plants were clipped at the ground level and were handled in the same manner as the first clipping.

Methods Used in Determining Available Soil Phosphorus

The following methods of extracting available phosphorus were used:

1. 0.5 molar sodium bicarbonate adjusted to a pH value of 8.5 with a 1:20 soil-solution ratio (29).

2. The Truog method, using 0.002 N H_2SO_4 buffered with $(NH_4)_2SO_4$ to a pH value of 3.0 and a 1:200 ratio of soil to extractant (37).

3. 0.1 N acetic acid employing a 1:40 soil-solution ratio (20).

4. Sodium acetate adjusted to a pH value of 4.85 with a 1:5 ratio of soil to extractant (1).

5. Bray's two methods: (a) 0.1 N HCl plus 0.03 N NH_4F employing soil-solution ratios of 1:50 and 5:50 respectively; and (b) 0.025 N HCl plus 0.03 N NH_4F with a soil-solution ratio of 5:50 (6).

Slight changes were made in some of these methods; particularly in the formation of color. However, the proportions of the reagents were usually kept the same. Some of these modifications will be discussed briefly in the following paragraphs.

In the sodium bicarbonate method, the color was developed on 40 ml.

aliquots which were placed in 100 ml. volumetric flasks. The pH of this filtrate was adjusted with 5 N HCl, using p-nitrophenol as the indicator. After the pH was adjusted, the volume was brought up to 76 ml. Then 20 ml. of ammonium molybdate-HCl solution and 4 ml. of stannous chloride were added. Ten minutes later the solutions were read on the Fisher AC Electrophotometer.

For the Truog procedure, the color was formed in 96 ml. aliquots of filtrate placed in 100 ml. volumetric flasks. Four ml. of ammonium molybdate-sulfuric acid solution and 6 drops of stannous chloride were used in developing the color.

In the acetic acid method, color was developed on 20 ml. aliquots in 100 ml. volumetric flasks. Then the volume was brought up to 97 ml. before the addition of 2 ml. of ammonium molybdate-sulfuric acid solution and 8 drops of stannous chloride. Color was also developed on the same filtrates using "Elon" (methyl -p- amino - phenol sulfate) as described by Graham (19). A 97 ml. aliquot plus 2 ml. ammonium molybdate-HCl solution and 1 ml. "Elon" were used in forming the color with this reducing agent.

With Bray's procedures, color was developed on 20 ml. aliquots of filtrate for both the 0.1 N and 0.025 N HCl extractants used. Three ml. of distilled water, 1 ml. ammonium molybdate-HCl solution, and 1 ml. amino-naphthol sulfonic acid were then added. After 15 minutes, the samples were read on the electrophotometer.

In the sodium acetate method, color was developed on 10 ml. and 15 ml. aliquots brought to a final volume of 25 ml. by the addition of the proper quantity of reagents described in the method.

Standard calibration curves, with and without the extracting agents, were prepared for each method. The standards were made by dissolving 0.2195 grams of potassium di-hydrogen phosphate in distilled water and bringing the final volume to 1 liter. From this 50 ppm phosphorus stock solution, 5 ppm and 10 ppm concentrations were prepared and used to make up the desired standards for the curves. The phosphorus content of the unknown extracts could then be determined by comparing their photometric readings with the standard curve. Samples were read on a Fisher Electrophotometer using a 650 A intensity Red Filter. The machine was zeroed with a reagent blank. Duplicate determinations were made on all of the soils tested.

Field Studies

Soils for this study were taken at a depth of 0-7 inches from the plots of the 1100 series (Alfalfa Rotation) on the Agronomy Department Farm at Perkins, Oklahoma. These soils are from upland area, which was developed from old alluvium. They are deep soils and are moderately permeable. Under virgin conditions, they were low in phosphorus and moderately acid. The characteristics of the profile resemble a Norge fine sandy loam (14).

These 1100 series plots are under an eight year alfalfa rotation with oats, barley, darso, and cotton included in the rotation. Table II shows the different fertilizer treatments which are being applied to these plots. The plots are divided into two equal parts with one half receiving lime. These limed plots have had limestone added whenever the soil tests showed a need for lime. The fertilizers were all broadcast annually on the alfalfa, except the rock phosphate and manure. These amendments were applied once every eight years and plowed under

TABLE II

FERTILIZER TREATMENTS OF ALFALFA ROTATION PLOTS (1100 SERIES) ON AGRONOMY FARM AT PERKINS, OKLAHOMA

Treatments	Rate*
None	
Superphosphate, 20% available P_2O_5	200 lbs.
Superphosphate, 45% available P_2O_5	89 lbs.
Rock phosphate, 33% total P_2O_5	575 lbs.
Manure	80 lbs. of nitrogen
Manure and rock phosphate	80 lbs. of nitrogen 575 lbs. of rock phosphate
Manure and superphosphate	80 lbs. of nitrogen 200 lbs. of 20% superphosphate
Manure, superphosphate and muriate of potash	80 lbs. of nitrogen 200 lbs. of 20% superphosphate 50 lbs. of muriate of potash
Superphosphate and muriate of potash	200 lbs. of superphosphate 50 lbs. of muriate of potash

* All treatments were broadcast annually on the alfalfa except rock phosphate and manure which were applied once every eight years prior to the seeding of alfalfa.

to a depth of 4 to 6 inches prior to the seeding of alfalfa.

The primary purpose of this study was to try to correlate the yields of alfalfa, obtained from these differentially fertilized plots with different chemical methods of testing soils for available phosphorus.

IV. RESULTS AND DISCUSSION

Calibration of Soil Tests for Available Phosphorus

In the $NaHCO_3$ method of extraction, color was developed by the modified Dickman and Bray (11) method using an ammonium molybdate-HCl solution and stannous chloride. Standards prepared in distilled water gave results similar to those made up in the extracting solution. The curve shown in Figure 1 was used in calculating the pounds of P_2O_5 per acre obtained by this method of extraction.

The curve used for the 0.1 N acetic acid procedure was slightly affected by the addition of the extractant to the standard when stannous chloride plus ammonium molybdate-H_2SO_4 solution was used. (Figure 2) However, when Elon plus ammonium molybdate-HCl solution was employed, there was no difference between curves produced from standards with or without the inclusion of the extracting reagent. (Figure 3) Elon gave less color development than stannous chloride, and thus a wider range of phosphorus values can be obtained with it than with stannous chloride. This can be seen in Figures 2 and 3 where the range with the stannous chloride was only 1 ppm phosphorus while the range with Elon expanded to 5 ppm on the Fisher electrophotometer using the 650 A Red Filter.

The curves prepared for sodium acetate and Bray's method's shown in Figures 4 and 5 also were unaffected by use of the standards prepared in the extracting solution. In preparing a curve for Troug's method of extraction, stannous chloride was used as the reducing agent. The inclusion

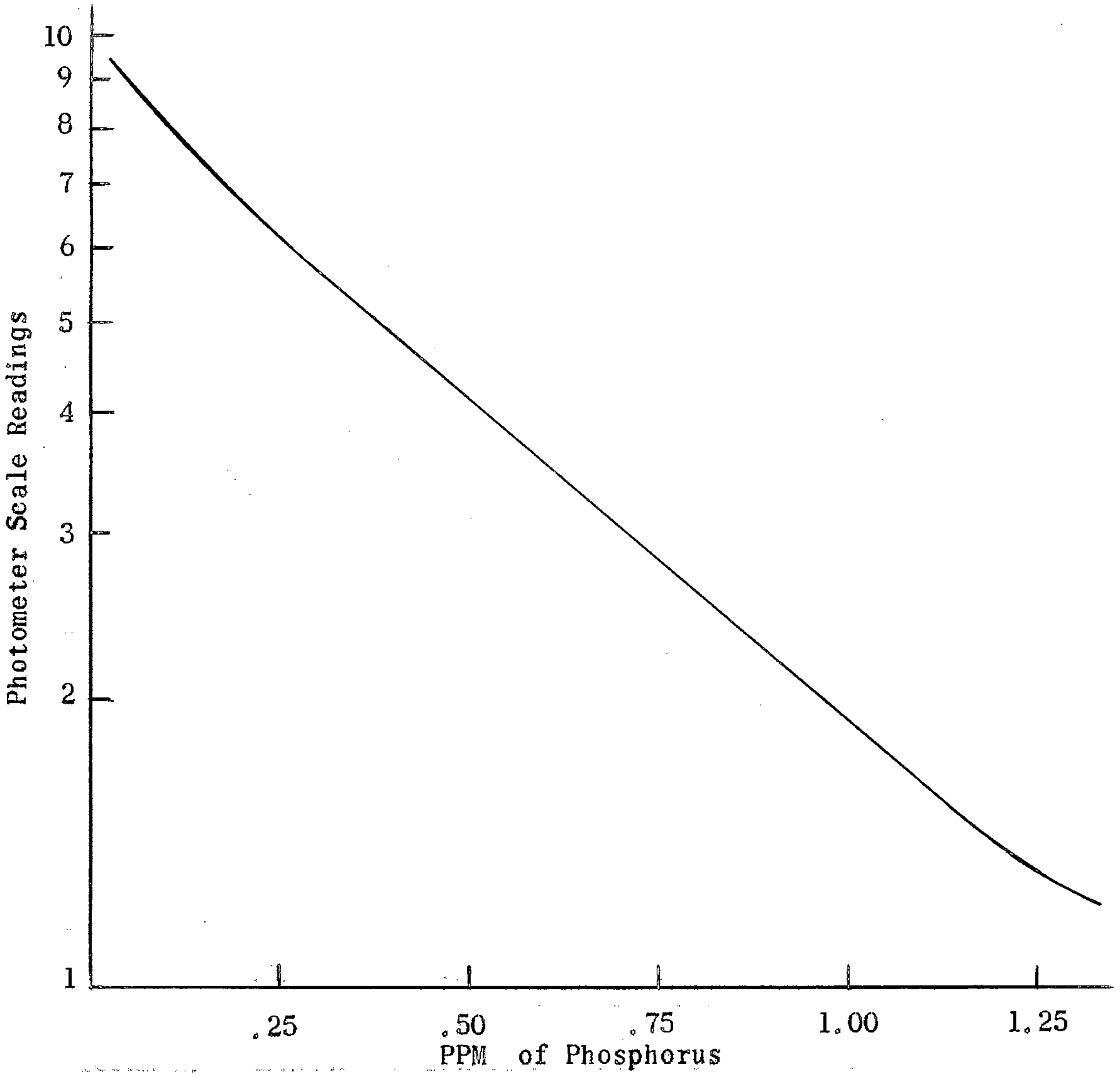

Figure 1. Standard Calibration Curve for the Determination of Available Phosphorus by the Sodium Bicarbonate Method of Extraction, Using an Ammonium Molybdate-HCl Solution and Stannous Chloride

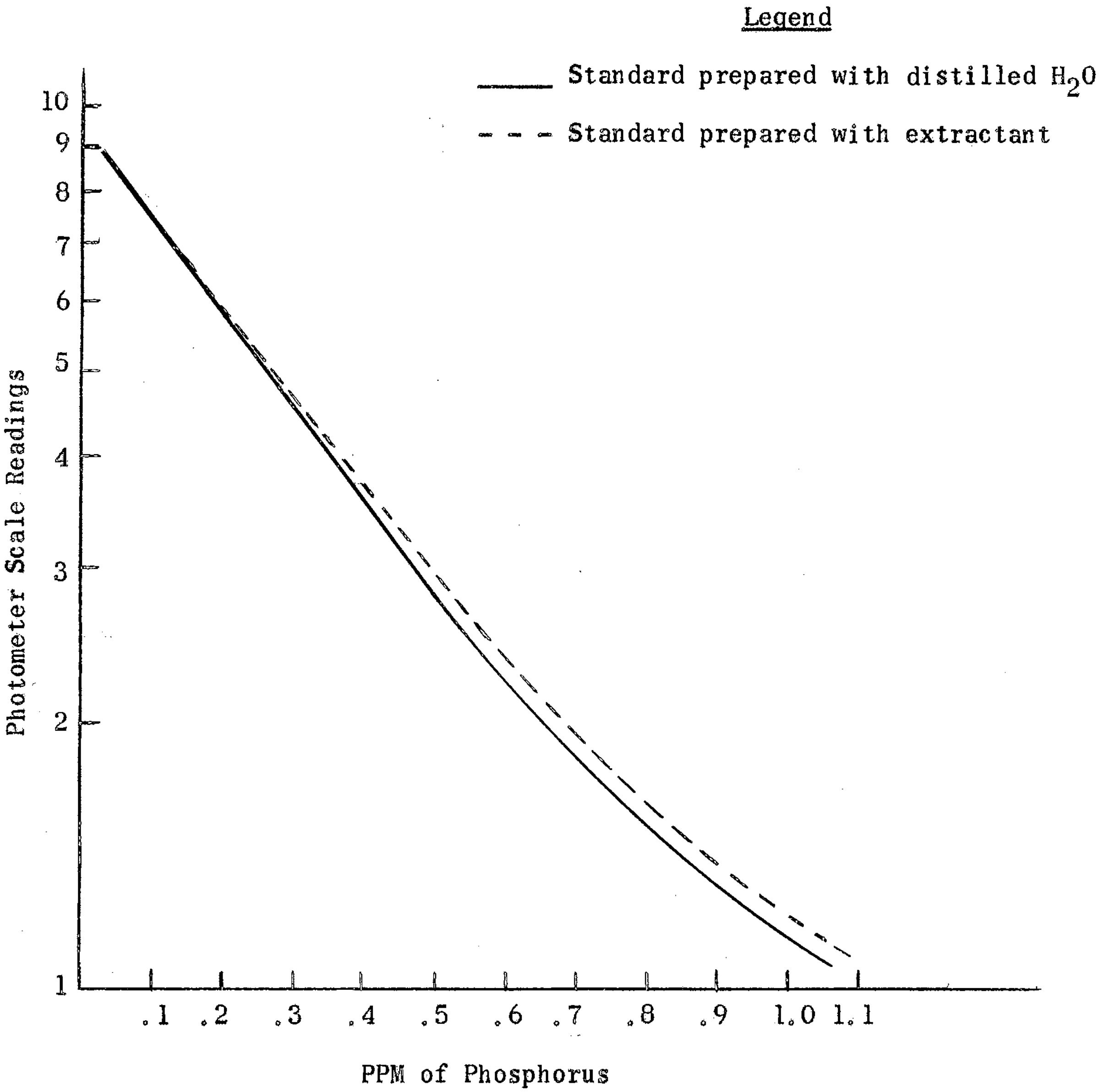

Figure 2. Standard Calibration Curve for the Determination of Available Phosphorus by the Acetic Acid Method of Extraction, Using Ammonium Molybdate-H_2SO_4 Solution and Stannous Chloride

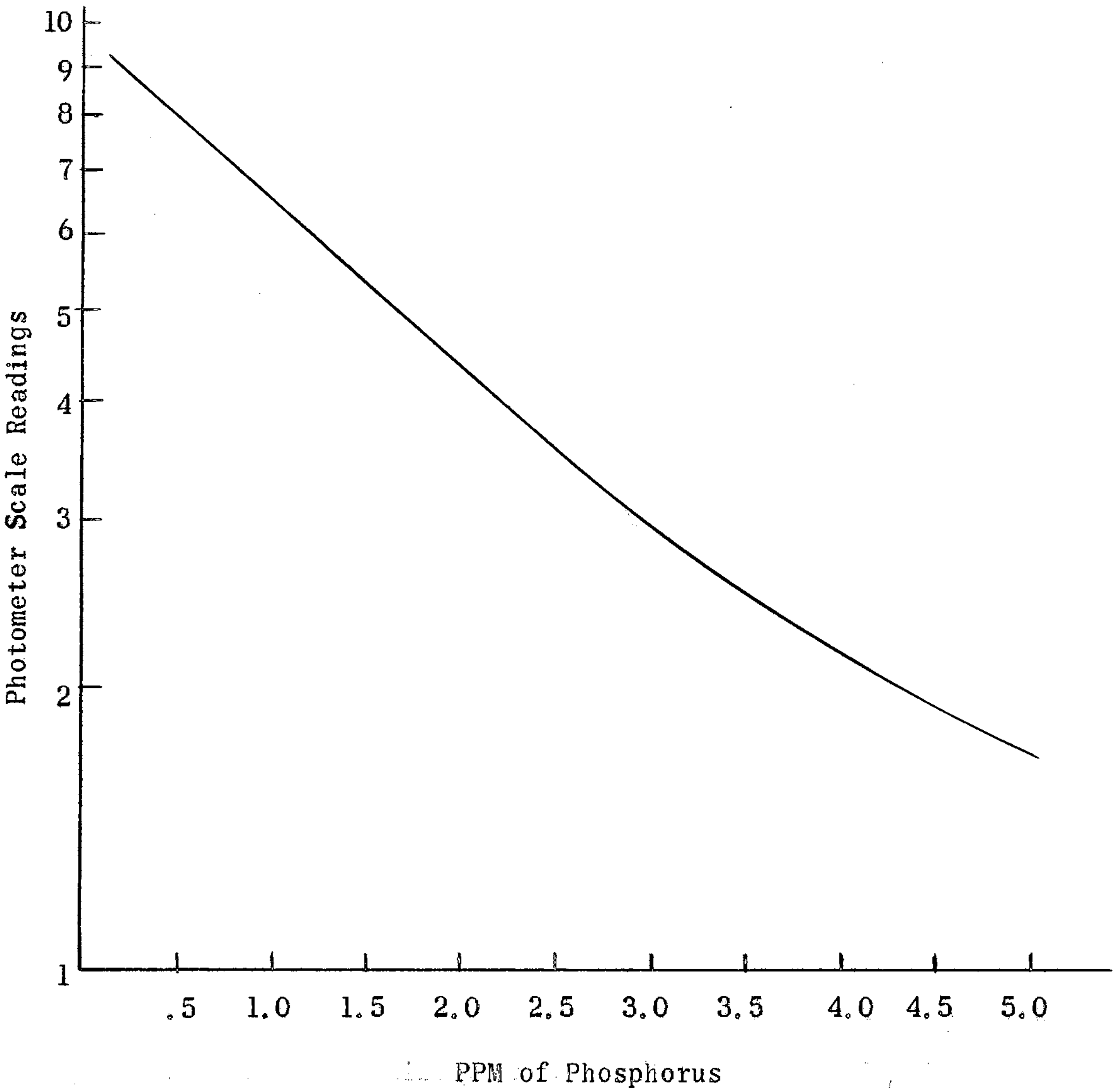

Figure 3. Standard Calibration Curve for the Determination of Available Phosphorus by the Acetic Acid Method of Extraction, Using Ammonium Molybdate-HCl Solution and Elon

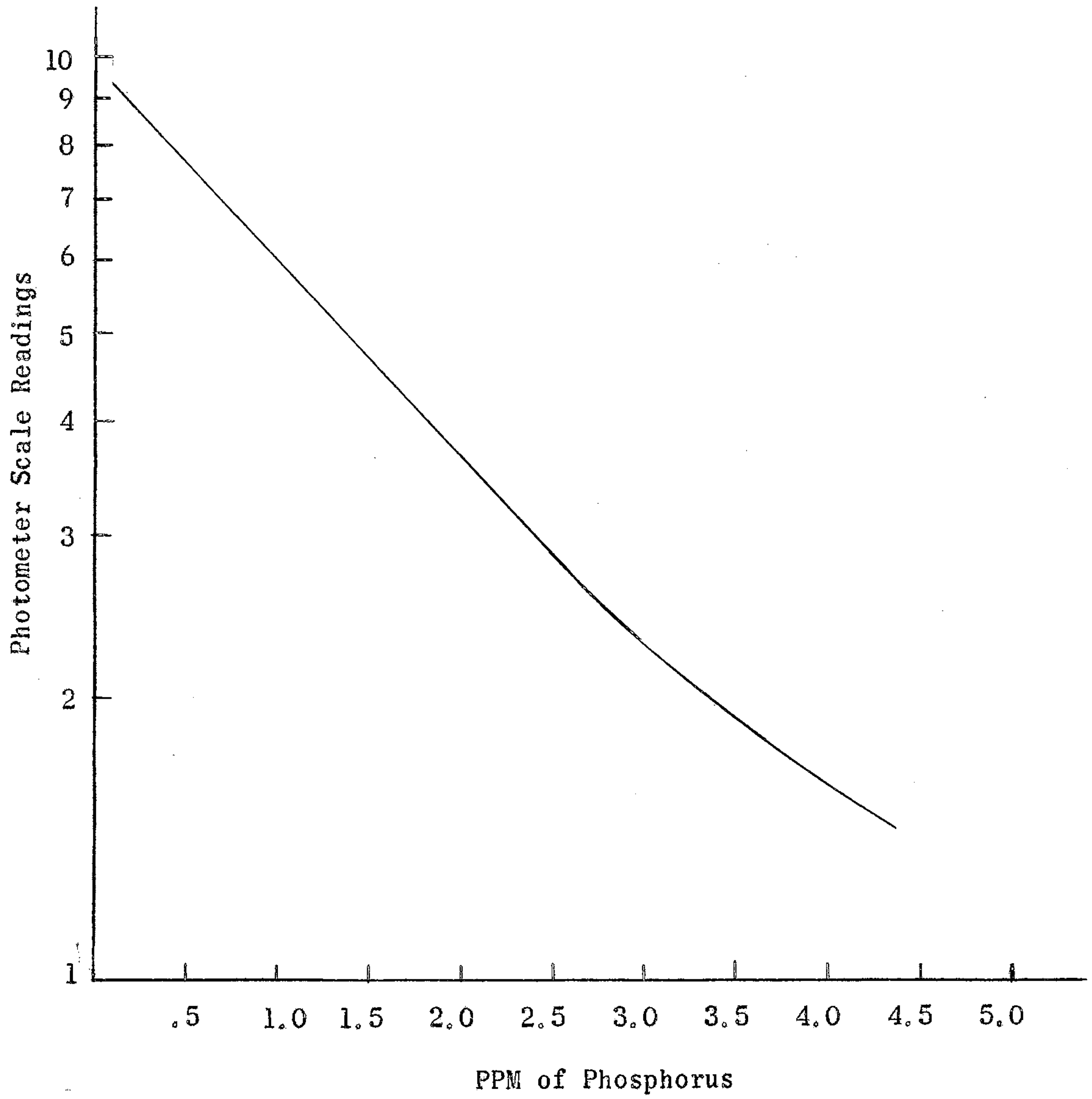

Figure 4. Standard Calibration Curve for the Determination of Available Phosphorus by Bray's Methods of Extraction, Using Ammonium Molybdate-HCl Solution and Amino-Naphthol-Sulfonic Acid

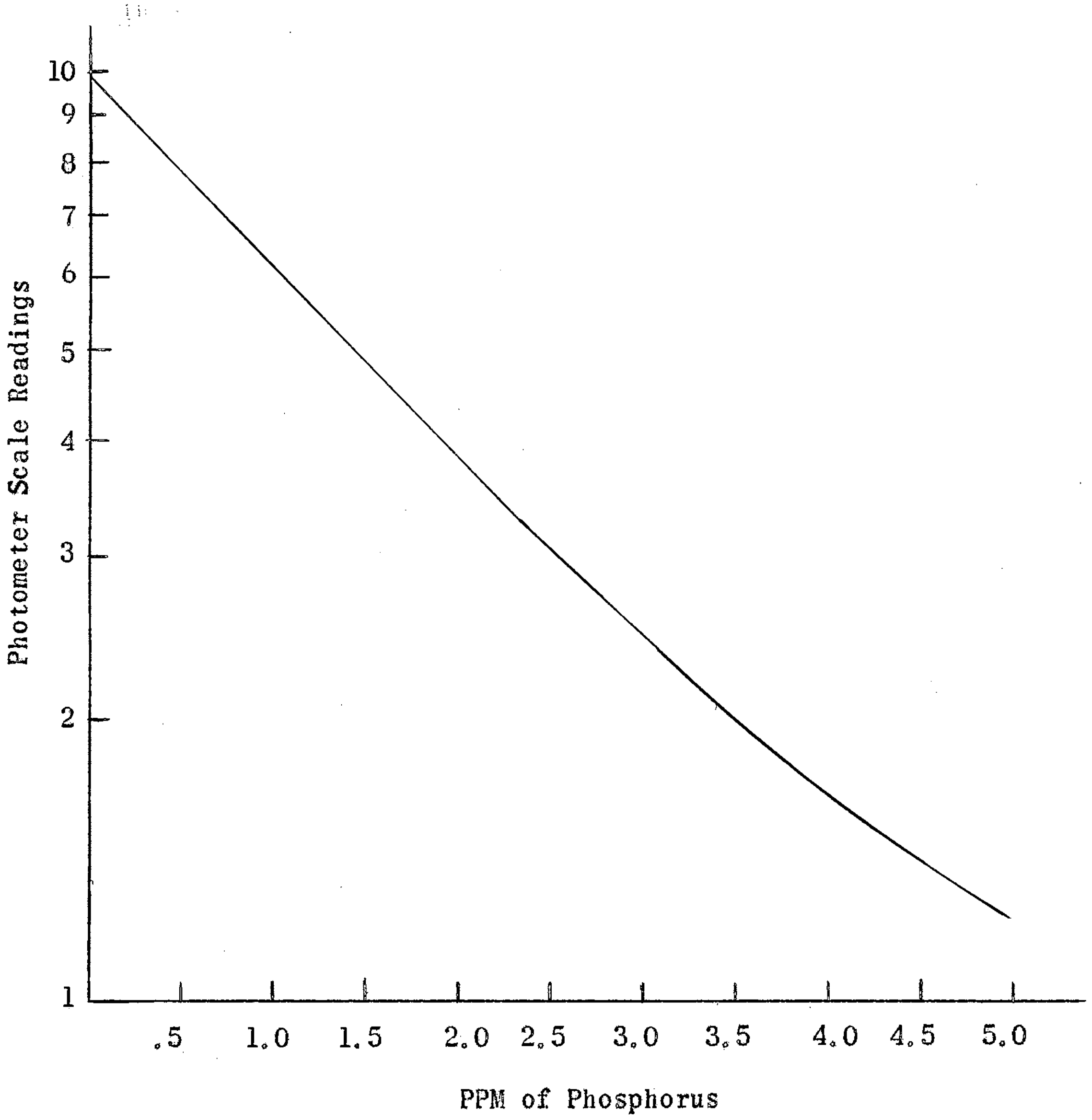

Figure 5. Standard Calibration Curve for the Determination of Available Phosphorus by the Sodium Acetate Method of Extraction, Using Ammonium Molybdate Solution and Amino-Naphthol-Sulfonic Acid

of the extracting solution in the standards gave only minor differences in color development as can be seen from the graph in Figure 6. The curve prepared from standards dissolved in the extracting solution was used in the determination of the pounds of P_2O_5 per acre in the soils.

Generally, in the preparation of curves, it was immaterial whether the standards were made up in the extractant or distilled water. Comparable results were obtained from standard curves prepared from distilled water using ammonium molybdate-HCl and ammonium molybdate-H_2SO_4 solutions in color development. Elon was used as the reducing agent in both cases.

Greenhouse Experiment

Observations were made on wheat plants, grown on different soils which received equivalent rates of 0, 20, and 40 pounds of available P_2O_5 per acre. Only slight differences were noted in physical appearances. Those plants which received the 20 and 40 pound treatments were slightly taller and had a greater amount of stooling than the plants in the check pots.

The vegetative yields of wheat grown in the phosphate treated pots are given in Table III. All of the soils, which had the 40 pounds of P_2O_5 treatment produced the most vegetative material at the first clipping. However, the 20 pound rate gave yields which fluctuated when compared to the yields on the untreated soils. This difference was due mainly to the fact that the plants were clipped at a uniform height of 3½ inches. However; these fluctuations were eliminated when the second clipping was made and combined with the first. The total vegetative yield on all soils increased from the addition of 20 and 40 pounds of

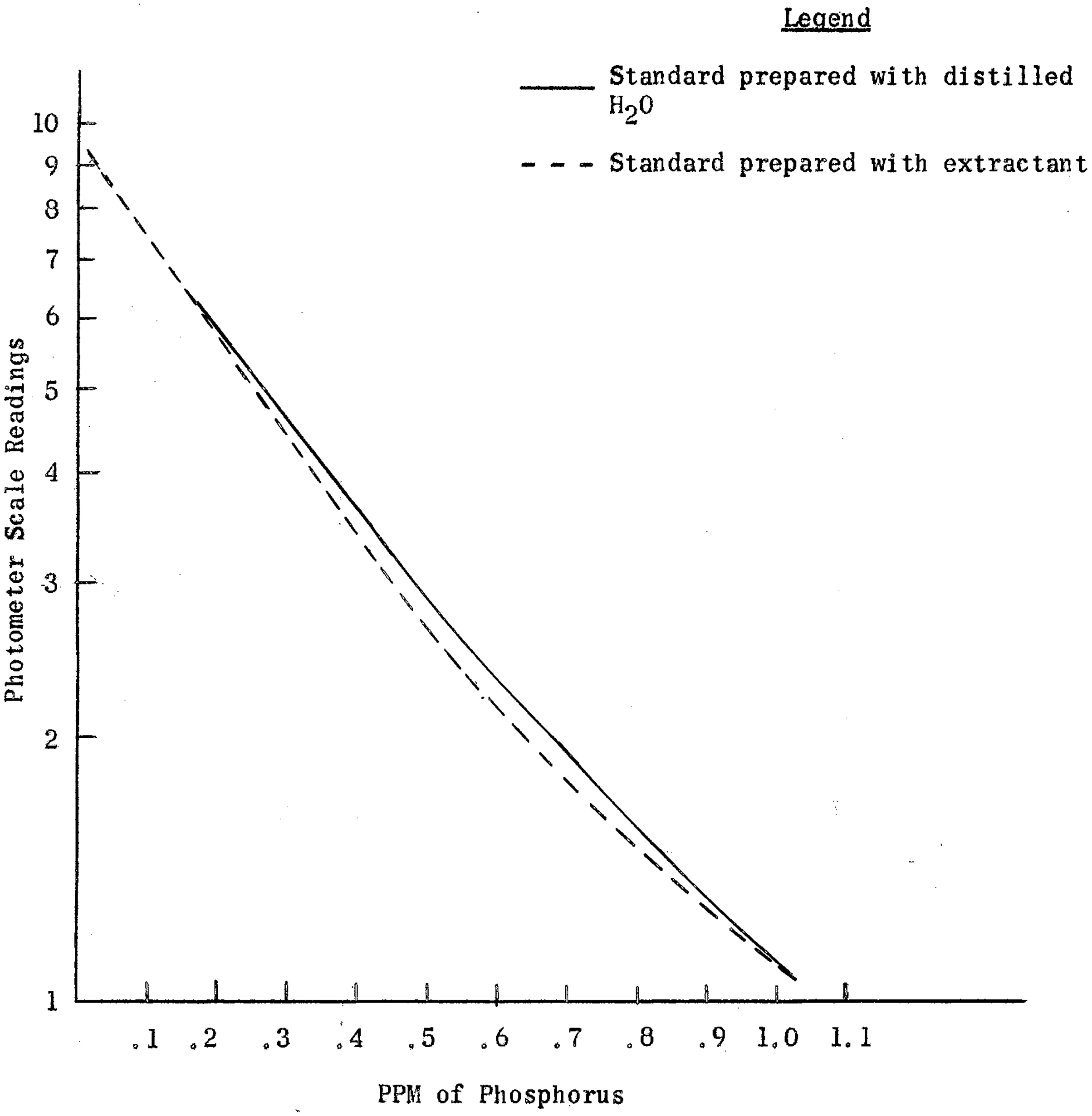

Figure 6. Standard Calibration Curve for the Determination of Available Phosphorus by Troug's Method of Extraction, Using Ammonium Molybdate-H_2SO_4 Solution and Stannous Chloride

TABLE III

MEAN VEGETATIVE YIELD OF WHEAT (GRAMS PER POT) GROWN IN THE GREENHOUSE ON SOILS RECEIVING DIFFERENT RATES OF PHOSPHATE FERTILIZATION

Soil	Treatments								
	Check			20 Lbs. P_2O_5/Acre			40 Lbs. P_2O_5/Acre		
	1st Clipping[1]	2nd Clipping[2]	Total Weight	1st Clipping	2nd Clipping	Total Weight	1st Clipping	2nd Clipping	Total Weight
Frederick	3.5*	10.9	14.4	3.3	12.3	15.6	4.0	12.1	16.1
Medford	4.4	13.6	18.0	5.8	13.6	19.4	5.7	14.3	20.0
Vici	3.6	12.4	16.0	4.1	13.1	17.2	4.3	13.6	17.9
Kingfisher A	1.9	12.6	14.5	1.9	13.2	15.1	2.0	13.4	15.4
Kingfisher B	4.5	13.4	17.9	4.1	14.3	18.4	4.7	13.7	18.4

* Mean of 4 replications.

[1] First clippings were made 66 days after planting. Plants were clipped at a uniform height of 3½ inches.

[2] Second clippings were taken 149 days after planting. Plants were cut at ground level.

P_2O_5 per acre; except for the Kingfisher B soil, on which plant yields were the same for the 20 and 40 pound applications. The increase in total vegetative yield from the 20 pound rate was greater per unit of P_2O_5 added than the 40 pound treatment as shown in Figure 7. The total vegetative yield tended to level off with the 40 pound treatment on the Kingfisher A and B soils and showed only a gradual increase for the Frederick, Medford, and Vici soils.

The increase in yield on the treated Frederick, Medford, and Vici soils was twice that of the Kingfisher A soils and 3 times that of the Kingfisher B soils for both the 20 pound and 40 pound treatments. From these results, one might possibly predict, without checking further that those treated soils which produced a slight increase in total vegetative yield are either inherently high in available phosphorus or perhaps they were fixing the added phosphorus in an unavailable form. Whereas, those soils which gave an increase in total vegetative yield are no doubt benefiting from the addition of phosphate.

Chemical Composition of Plants

Data in Table IV show that in most cases the percentages of total phosphorus in plants growing on the soils treated with 20 and 40 pounds of P_2O_5 per acre were slightly higher than those found in the plants grown on the check pots. However, on the Kingfisher A and B soils the total phosphorus percentages of the plants were much less for the second cutting than for the first cutting. An explanation of this difference between the second and first clipping in the Kingfisher A and B soils, might be attributed to the fact that both of these soils originally contained a very high level of available phosphorus. Another factor which

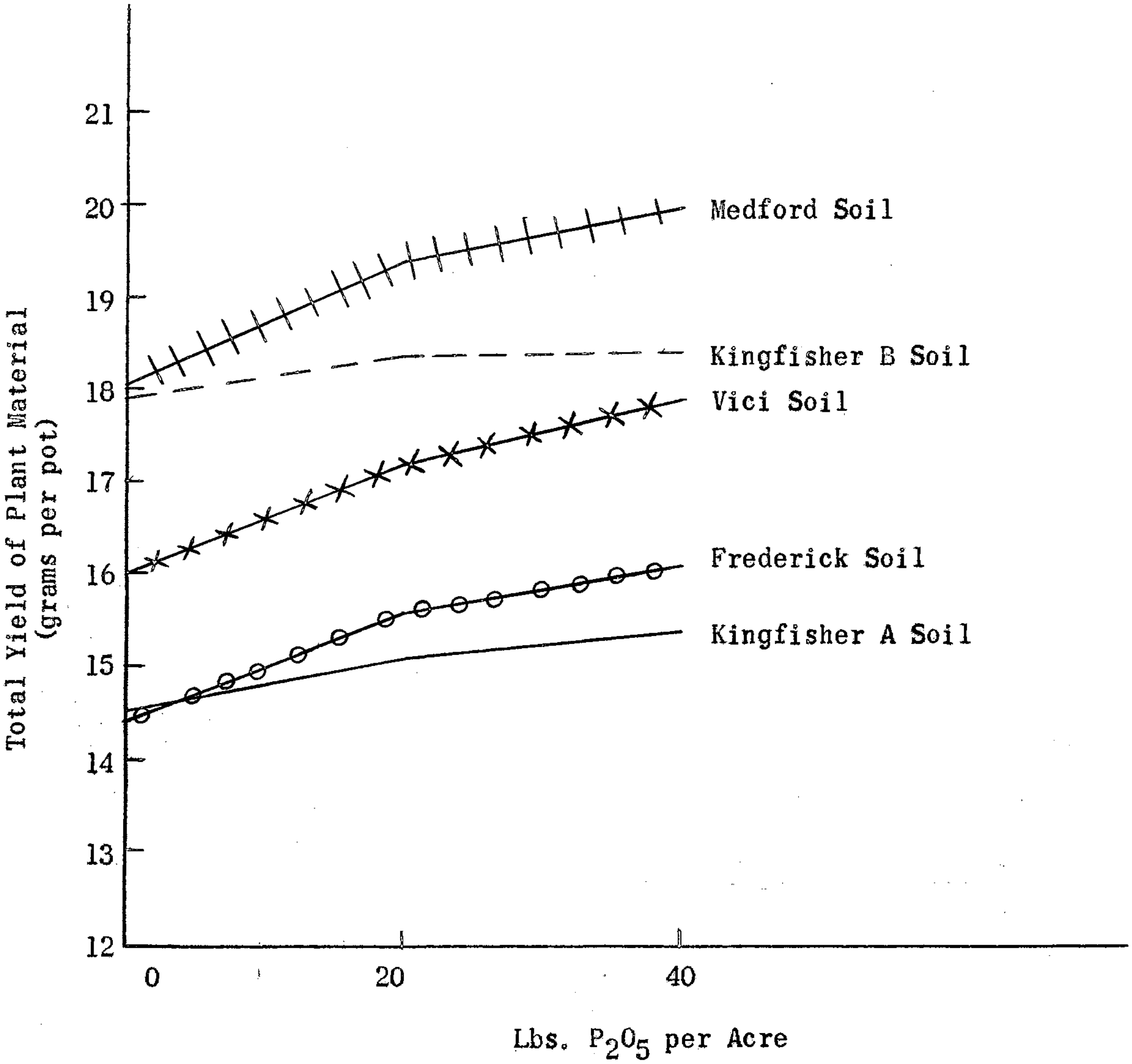

Figure 7. Vegetative Yield Response of Wheat Grown in the Greenhouse on Soils Which Received Different Increments of P_2O_5 per Acre

TABLE IV

PERCENTAGE OF TOTAL PHOSPHORUS FOUND IN WHEAT PLANTS GROWN IN THE GREENHOUSE ON SOILS WITH DIFFERENT LEVELS OF PHOSPHATE FERTILIZATION

Soil	Treatments					
	1st Clipping			2nd Clipping		
	Check	20# P_2O_5	40# P_2O_5	Check	20# P_2O_5	40# P_2O_5
Frederick	0.28*	0.30	0.32	0.30	0.29	0.32
Medford	0.29	0.27	0.28	0.29	0.30	0.28
Vici	0.24	0.27	0.33	0.26	0.30	0.34
Kingfisher A	0.40	0.41	0.44	0.30	0.34	0.32
Kingfisher B	0.44	0.53	0.54	0.34	0.40	0.38

* Mean value of 4 replications.

has a bearing on this difference is that the phosphorus concentration in plants is usually greater during the early growth of the plant. To a certain extent, the plant composition is affected by the amount of nutrients in the soil. Therefore, from these results you might expect a soil with a large amount of native available phosphorus to produce plants with a higher total phosphorus percentage than a soil which was inherently lower in available phosphorus. This is no doubt true for the plants on the Kingfisher A and B soils which were high in available phosphorus.

The total phosphorus uptake by wheat plant is shown in Table V. The wheat plants grown on the soils which received 20 and 40 pounds of P_2O_5 per acre respectively, absorbed more phosphorus in nearly all cases, than those which were grown in the untreated soils. Thus, there seems to be a general relationship between the amount of phosphate supplied to the plant and the amount taken up by the plant.

The nitrogen percentage of the harvested vegetative plant material generally decreased with each increment of P_2O_5 applied to the soils (Table VI). The plants grown on the Kingfisher A and B soils did not follow this trend for the first clipping. In the second clipping, the plants grown on some of the soils had higher percentages of nitrogen than in the first clipping. This may be partially explained by the application of the equivalent of 200 pounds of ammonium nitrate after the first clipping. The total nitrogen uptake also followed the same general trend by decreasing in the amount absorbed with each increment of P_2O_5 applied to the soils. (Table VII). Thus, the addition of phosphorus to these soils depressed the amount of nitrogen taken up by the plants.

TABLE V

TOTAL PHOSPHORUS (MGMS. PER POT) ABSORBED BY THE WHEAT PLANTS GROWN IN THE GREENHOUSE ON SOILS WHICH RECEIVED DIFFERENT RATES OF PHOSPHATE FERTILIZER

Soil	Treatments								
	1st Clipping			2nd Clipping			Total		
	Check	20# P_2O_5	40# P_2O_5	Check	20# P_2O_5	40# P_2O_5	Check	20# P_2O_5	40# P_2O_5
Frederick	9.8	9.9	12.8	32.7	35.7	38.7	42.5	45.6	51.5
Medford	12.8	15.7	16.0	39.4	40.8	40.0	52.5	56.5	56.0
Vici	8.6	11.1	14.2	32.2	39.3	46.2	40.8	50.4	60.4
Kingfisher A	7.6	7.8	8.8	37.8	44.9	42.9	45.4	52.7	51.7
Kingfisher B	19.8	21.7	25.4	45.6	47.2	52.1	65.4	68.9	77.5

TABLE VI

PERCENTAGE OF TOTAL NITROGEN FOUND IN WHEAT PLANTS GROWN IN THE GREENHOUSE ON SOILS WITH DIFFERENT LEVELS OF PHOSPHATE FERTILIZATION

Soil	Treatments					
	1st Clipping			2nd Clipping		
	Check	20# P_2O_5	40# P_2O_5	Check	20# P_2O_5	40# P_2O_5
Frederick	2.79*	2.65	2.45	2.96	2.65	2.54
Medford	3.39	3.10	2.71	3.07	2.80	2.49
Vici	2.30	2.13	1.99	2.53	2.64	2.52
Kingfisher A	1.76	1.90	1.84	2.44	2.45	2.24
Kingfisher B	2.40	2.49	2.24	2.52	2.33	2.44

* Mean value of duplicate determinations on 4 replications.

TABLE VII

TOTAL NITROGEN (MGMS. PER POT) FOUND IN WHEAT PLANTS GROWN IN THE GREENHOUSE ON SOILS WHICH RECEIVED DIFFERENT RATES OF PHOSPHATE FERTILIZER

Soil	Treatments								
	1st Clipping			2nd Clipping			Total		
	Check	20# P_2O_5	40# P_2O_5	Check	20# P_2O_5	40 P_2O_5	Check	20# P_2O_5	40# P_2O_5
Frederick	97.6	87.4	98.0	322.6	325.9	307.3	420.2	413.3	405.3
Medford	149.2	179.8	154.5	417.5	380.8	356.1	566.7	560.6	510.6
Vici	82.8	87.3	85.6	313.7	345.8	342.7	396.5	433.1	428.3
Kingfisher A	33.4	36.1	36.8	307.4	323.4	300.3	340.8	359.5	337.0
Kingfisher B	108.0	102.1	105.3	337.7	333.2	334.3	445.7	435.3	439.6

Chemical Studies of Soils used in the Greenhouse

The results of the chemical tests for available phosphorus on the soils used in the greenhouse experiment are given in Table VIII. All the methods showed that the soil from Medford was the lowest in available phosphorus. The general order of soils, ranging from low to high, in available phosphorus, was as follows: Medford, Frederick, Vici, Kingfisher A, and Kingfisher B. An exception to this order was found by the $NaHCO_3$ and sodium acetate procedures in which the Frederick soil was higher in available phosphorus than the Vici soil.

The 0.1 N acetic acid method extracted a large amount of available phosphorus from all the soils tested with both stannous chloride and Elon used as reducing agents. Also a large amount of available phosphorus was removed by Bray's 0.1 N HCl procedure using soil solution ratios of 1 to 50 or 5 to 50. However, when Bray's 0.025 N HCl test was used the amount of available phosphorus extracted was approximately one half that removed by the 0.1 N HCl method. The smallest amount of available phosphorus was removed by sodium acetate. $NaHCO_3$ extracted slightly more available phosphorus than the sodium acetate procedure. Truog's method gave results similar to Bray's 0.1 N HCl test with a soil-solution ratio of 5 to 50.

A method of correlating these results was fabricated by substituting the lettered values, taken from the response charts devised for each particular method of extraction, for the pounds per acre of available P_2O_5 (Table IX). This data conversion is shown in Table X. By comparing the soil test information from this table with the growth response to the additions of 20 and 40 pounds of P_2O_5 per acre on the various soils in the greenhouse, the following observations were made.

TABLE VIII

AMOUNTS OF AVAILABLE PHOSPHORUS (POUNDS OF P_2O_5) REMOVED BY DIFFERENT METHODS OF EXTRACTION ON SOILS USED IN THE GREENHOUSE EXPERIMENT

Soil	$NaHCO_3$	Troug	Acetic Acid		Bray's Extraction Methods			Sodium Acetate
			($SnCl_2$)	(Elon)	.1N HCL (1-50)	.1N HCl (5-50)	.025N HCl (5-50)	
Frederick	38.5*	102.4	236.8	264.2	195.5	123.7	62.9	17.2
Medford	29.3	49.5	114.8	166.0	114.5	70.6	54.3	9.7
Vici	34.6	150.5	247.3	273.6	314.9	166.0	64.0	14.9
Kingfisher A	76.0	223.4	337.4	377.4	372.1	251.9	129.4	64.1
Kingfisher B	171.8	426.8	522.1	542.3	641.9	455.9	252.3	107.3

* Mean value of duplicates

TABLE IX

RESPONSE CHARTS FOR SODIUM BICARBONATE, ACETIC ACID AND BRAY'S METHODS OF EXTRACTION FOR AVAILABLE PHOSPHORUS

Bray's Method		NaHCO3**		Acetic Acid	
Lettered Value*	Lbs. P_2O_5/A.	Value	Lbs. P_2O_5/A.	Value	Lbs. P_2O_5/A.
L-	$\leqslant$46			Very low	0-14
L	47-60	Low	0-25		
L+	61-74			Low	15-43
S-	75-88				
S	89-104	Medium	25-50	Medium	44-65
S+	105-122				
M-	123-140			Medium +	66-94
M	141-156	High	50-100		
M+	157-172			High	95-154
H-	173-186				
H	187-209	Very high	100+	Very high	155+
H+	$\geqslant$210				

* L = Low

S = Slight

M = Medium

H = High

** Below 25, a response
Between 25 and 50, a probable response
Over 50, a response unlikely

TABLE X

LEVELS OF AVAILABLE PHOSPHORUS FOUND IN SOILS USED IN THE GREENHOUSE AS INTERPRETED FROM THE RESPONSE CHARTS

Soil	$NaHCO_3$	Acetic Acid		Bray's Methods		
		($SnCl_2$)	(Elon)	.1N HCl		.025N HCl
				(1-50)	(5-50)	(5-50)
Frederick	M	VH	VH	H	M	L+
Medford	M	H	H	S+	L+	L
Vici	M	VH	VH	H+	M+	L+
Kingfisher A	H	VH	VH	H+	H+	M-
Kingfisher B	VH	VH	VH	H+	H+	H+

According to the results obtained by the $NaHCO_3$ method, you might expect a response to phosphate fertilizer on the Frederick, Medford, and Vici soils. Table III shows a response from the addition of 20 and 40 pounds P_2O_5 to these soils. The response chart value gives a doubtful response to added phosphate on the Kingfisher A soil. On the Kingfisher B soil, which had a very high soil test reading, no response was derived from the 40 lb. P_2O_5 treatment over the 20 pound rate. Also there was only a negligible increase from the initial 20 pound application. Thus this test seemed to agree very well with growth response. Those soils testing the lowest responded the most to phosphate additions, while those soils having the highest test values displayed the least response.

The 0.1 N acetic acid method gave very high readings in all cases, but one. This one was a high value on the Medford soil. From the interpretation of these results, one would not expect any of the soils to respond to phosphate fertilization. However, there was an increase in total vegetative yield from the additions of 20 and 40 pounds P_2O_5 per acre, to the Medford, Vici, and Frederick soils. The readings taken from the response charts for acetic acid were the same regardless of the reducing agent used. On the basis of pounds of P_2O_5 per acre, the Elon reducing agent gave higher values.

For Bray's methods, the readings tended to correlate fairly well with crop response when both the 0.025 N HCl and the 0.1 N HCl with a soil solution ratio of 5-50 were used. Values from both of these procedures corresponded closely as to highs and lows; but the 0.1 N HCl extraction removed approximately twice as much available phosphorus as the 0.025 N HCl method. The interpretation of 0.1 N HCl (5-50 soil solution ratio) test showed a response might be expected for the Medford soil, a response was unlikely on the Frederick and Vici soils, and no response would be expected on the Kingfisher A and Kingfisher B soils. However, when a soil solution ratio of 1 to 50 was used with 0.1 N HCl, all of the soils gave a high reading, except the Medford soil which showed that a doubtful response might be expected. When the 0.025 N HCl method was used, the interpretations coincided very closely with crop response. The Medford soil showed a low soil test value with response expected. The Frederick and Vici soils gave a low reading with a response also expected. While the value on the Kingfisher A soil was a medium minus with response likely to occur, and the Kingfisher B soil had a high plus reading with no response expected.

Response charts for the Truog and sodium acetate method were unavailable, making it impossible to correlate these extraction methods in the same manner as the sodium bicarbonate, acetic acid, and Bray's methods.

Field Studies

All of the different chemical procedures were consistent in extracting the least amount of available phosphorus from the untreated soils obtained from the alfalfa rotation plots at Perkins, (Table XI). The sodium acetate method and the $NaHCO_3$ procedures again extracted smaller amounts of available phosphorus than the other methods. Truog's, 0.1 N acetic acid, and Bray's 0.1 N HCl procedure all extracted the largest amount of available P_2O_5 from the plots which were treated with rock phosphate alone and rock phosphate plus manure. The $NaHCO_3$, Bray's 0.025 N HCl, and sodium acetate methods removed the largest amount of

TABLE XI

AMOUNTS OF AVAILABLE PHOSPHORUS (POUNDS OF P_2O_5) REMOVED BY DIFFERENT METHODS OF EXTRACTION ON THE SOILS OBTAINED FROM THE ALFALFA ROTATION PLOTS (1100 SERIES) AT PERKINS

Treatments**	$NaHCO_3$	Troug	Acetic Acid		Bray's Methods .1N HCl		Bray's Methods .025N HCl	Sodium Acetate	
			($SnCl_2$)	(Elon)	(1-50)	(5-50)	(5-50)	(10 ml.)	(15 ml.)
None	9.2*	28.1	73.2	102.8	46.7	19.8	15.4	5.8	28.0
Lime	9.2	23.8	96.2	134.9	55.0	19.5	15.5	8.0	40.0
Sp 20%	29.9	62.9	103.5	145.3	114.8	72.0	54.9	8.6	24.8
Sp 20% + L	24.5	53.3	82.4	134.9	92.6	55.3	34.3	10.3	42.0
Sp 45%	30.9	70.5	125.5	151.4	109.5	76.3	54.9	10.3	30.4
Sp 45% + L	41.9	95.3	181.4	211.3	139.5	100.2	73.4	16.6	51.3
Rp	20.3	151.9	239.1	237.8	205.1	153.3	38.1	10.8	29.2
Rp + L	17.2	151.9	231.7	241.5	171.6	129.4	28.8	14.3	40.8
M	14.3	47.6	75.6	107.1	67.8	32.5	23.7	8.1	28.8
M + L	11.4	29.5	112.2	168.4	60.1	24.4	19.5	9.7	45.7
M & Rp	30.1	241.7	313.3	327.9	286.2	221.9	52.4	12.0	34.6
M & Rp + L	25.4	223.4	283.0	306.6	276.5	217.6	41.0	12.6	43.3
M & Sp	38.5	78.1	114.5	144.8	121.7	88.8	72.5	12.6	45.8
M & Sp + L	38.5	70.5	142.9	181.1	108.8	76.5	63.9	14.9	58.0
M, Sp & K	44.2	78.1	139.2	167.0	127.1	98.7	78.7	16.0	41.4
M, Sp & K + L	42.8	70.5	131.0	167.9	121.3	81.6	65.8	16.0	39.5
Sp & K	29.3	57.2	96.6	129.3	94.5	65.3	54.3	9.1	29.7
Sp & K + L	21.3	45.7	96.2	123.5	85.9	50.5	41.0	11.4	42.9

* Mean value of duplicates.

** Sp = Superphosphate, Rp = Rock phosphate, M = Manure, L = Lime, K = Muriate of potash.

available P_2O_5 from the manure, superphosphate plus KCl plot. These same tests also extracted large amounts of available P_2O_5 from the plots which received manure plus superphosphate. The soils from the limed plots usually contained less available phosphorus than the unlimed plots. Ordinarily the application of lime tends to increase the availability of soil phosphorus. However, the soils from the limed and unlimed plots did not show an appreciable difference in pH.

An attempt was made to correlate these chemical tests with the yields of alfalfa obtained from these alfalfa rotation plots. (Table XII). Table XIII gives the adjective values assigned to the yields of alfalfa. These values corresponded to the letter values found in the response charts for the various procedures. The response charts for the $NaHCO_3$ and Bray method were modified somewhat from those used in connection with the greenhouse correlation studies. By comparing the values of the alfalfa yields with those of the response chart (Table XIV), an arbitrary correlation was devised. When the tests gave a high reading one would expect to obtain a high yield of alfalfa, if phosphorus was the limiting factor of plant growth.

On all of the unlimed plots, a good correlation was obtained between the sodium bicarbonate test and yield of alfalfa as shown in Table XV. Practically the same results were obtained on the limed plots, except those tests on the rock phosphate, manure, and manure plus superphosphate plots showed a fair correlation; while that of manure plus rock phosphate gave a fair to poor relationship. In most all cases, the amount of available phosphorus extracted by the sodium bicarbonate extractant was less on the limed plots than on the unlimed plots, with the yields generally being greater on the limed plots. This no doubt

TABLE XII

YIELDS OF ALFALFA HAY (TONS PER ACRE) FROM THE ALFALFA ROTATION PLOTS (1100 SERIES) AT PERKINS

Treatments*	1951	1952	1953	3 Yr. Average
None	.50	.58	.42	.50
L	.87	.91	.85	.88
Sp 20%	.92	1.75	1.74	1.47
Sp 20% + L	1.74	2.25	2.48	2.16
Sp 45%	.92	1.73	1.64	1.43
Sp 45% + L	1.82	2.29	2.73	2.28
Rp	.94	1.89	1.77	1.55
Rp + L	2.04	2.40	2.62	2.35
M	1.76	2.01	1.60	1.79
M + L	2.57	2.41	2.16	2.38
M + Sp	2.30	2.42	2.18	2.30
M + Sp + L	2.95	2.98	3.18	3.04
M + Rp	2.42	2.66	2.29	2.46
M + Rp + L	3.14	3.07	3.13	3.11
M + Sp + K	2.18	2.60	2.16	2.31
M + Sp + K + L	2.49	3.02	3.20	2.90
Sp + K	1.13	1.78	1.80	1.57
Sp + K + L	1.60	2.18	2.28	2.02

* Sp = Superphosphate
Rp = Rock phosphate
M = Manure
L = Lime
K = Muriate of potash

TABLE XIII

CONVERSION OF ALFALFA YIELDS FROM DIFFERENTIALLY FERTILIZED PLOTS INTO ADJECTIVE VALUES

Treatments*	Yield Level**	Alfalfa Yield (Tons/A.)	Percent Increase
None	L-***	.50	
Lime	L	.88	76
Sp 45%	L+	1.43	186
Sp 20%	L+	1.47	194
Rp	M-	1.55	201
Sp + K	M-	1.57	214
M	M-	1.79	258
Sp + K + L	M	2.02	304
Sp 20% + L	M+	2.16	332
Sp 45% + L	M+	2.28	356
M + Sp	M+	2.30	360
M + Sp + K	M+	2.31	362
Rp + L	M+	2.35	370
M + L	M+	2.38	376
M + Rp	H-	2.46	392
M + Sp + K + L	H	2.90	480
M + Sp + L	H+	3.04	508
M + Rp + L	H+	3.11	522

* Sp = Superphosphate
Rp = Rock phosphate
M = Manure
K = Muriate of potash
L = Lime

** Devised Table for Alfalfa Yield (Tons/A.) used in making conversions

L- = .00-0.50
L = .50-1.00
L+ = 1.00-1.50
M- = 1.50-1.80
M = 1.80-2.10
M+ = 2.10-2.40
H- = 2.40-2.70
H = 2.70-3.00
H+ = 3.00+

*** L = Low
M = Medium
H = High

TABLE XIV

REVISION OF THE SODIUM BICARBONATE AND BRAY'S RESPONSE CHARTS

Lettered Value	Sodium Bicarbonate (Lbs. P_2O_5/Acre)	Bray's Methods (Lbs. P_2O_5/Acre)
L-*	0-10	<45
L	10-15	47-74
L+	15-20	75-88
M-	20-26	89-104
M	26-33	105-140
M+	33-40	141-156
H-	40-60	157-172
H	70-80	173-209
H+	80 +	210 +

* Revised so that the lettered values of the Response Charts would correspond to the adjective yield values given to alfalfa in Table XIII

TABLE XV

CORRELATION OF THE YIELDS OF ALFALFA WITH DIFFERENT CHEMICAL TESTS

Treatments*	Yield Value**	Test Values***					
		$NaHCO_3$			Bray's Methods		
			$(SnCl_2)$	(Elon)			
None	L-	L-	M+	H	L-	L-	L-
Lime	L	L-	H	H	L	L-	L-
Sp 20%	L+	M	H	H	M	L	L
Sp 20% + L	M+	M-	M+	H	M-	L	L-
Sp 45%	L+	M	H	H	M	L+	L
Sp 45% + L	M+	H-	H+	H+	M	M-	L
Rp	M-	M-	H+	H+	H	M+	L-
Rp + L	M+	L+	H+	H+	H-	M	L-
M	M-	L	M+	H	L	L-	L-
M + L	M+	L	H	H+	L	L-	L-
M + Rp	H-	M	H+	H+	H+	H+	L
M+ Rp + L	H+	M-	H+	H+	H+	H+	L-
M + Sp + L	M+	M+	H	H	M	M-	L
M + Sp +L	H+	M+	H	H+	M	L+	L
M + Sp + K + L	M+	H-	H	H+	M	M-	L+
M + Sp + K + L	H	H-	H	H+	M	L+	L
Sp + K	M-	M	H	H	M-	L	L
Sp + K + L	M	M-	H	H	L+	L	L-

* Sp = Superphosphate, Rp = Rock phosphate, M = Manure, K = Muriate of potash, L = Lime

** Taken from Table XIII

*** Taken from Table XI and XIV

has a direct bearing upon the correlation of the test with the yields on these limed plots.

Bray's 0.1 N HCl with a 1-50 soil-solution ratio gave good correlations between the soil test values and yields on all of the unlimed plots, except on the rock phosphate plot which showed a fair to good relationship. However, on the limed plots, this method correlated well on all but the manure and manure plus superphosphate plus muriate of potash plots. When a soil-solution ratio of 5-50 was used with this extractant the degree of correlation was not as good as the 1-50 soil-solution ratio.

The Bray, 0.025 N HCl procedure showed low values on all of the soils with varying yield levels. It did not give good relationships on either the limed or the unlimed plots. The acetic acid procedure likewise showed fair to poor degrees of correlation in most cases, because high test values were obtained on nearly all of the soil plots tested.

Thus, the sodium bicarbonate method gave the best correlation on all plots, while the Bray 0.1 N HCl test with a soil-solution ratio of 1-50 also gave reliable predictions.

The manure plots tended to have much poorer correlation than the plots which received phosphate fertilizers. Perhaps the other beneficial effects of manure aside from fertility may partially account for the great deviation. Also those plots which received lime did not correlate as well as the unlimed plots.

V. SUMMARY AND CONCLUSIONS

Greenhouse and field experiments were used to evaluate the following methods of extraction for available phosphorus: Truog's 0.002 N H_2SO_4 buffered at a pH of 3.0 with a soil solution ratio of 1 to 200; 0.5 molar $NaHCO_3$ adjusted at a pH of 8.5 with a soil-solution ratio of 1 to 20: 0.1 N acetic acid with a soil-solution ratio of 1 to 40; 0.1 N HCl and 0.025 N HCl plus 0.03 N NH_4F methods with different soil-solution ratios, and sodium acetate adjusted to a pH value of 4.85 with a 1 to 5 ratio of soil to extractant.

Greenhouse studies were made with soils collected from Medford, Vici, Frederick, and Kingfisher. The soils were treated with 0, 20, and 40 pounds available phosphorus per acre plus a constant rate of nitrogen. Vegetative wheat yields and response to phosphate fertilizers were compared with chemical tests for available phosphorus. Effects of these treatments on nitrogen and phosphorus uptake by plants were also determined. An attempt was made to correlate alfalfa yields with soil tests for available phosphorus. The data were obtained from alfalfa rotation plots which received the following combinations of fertilizer: 20% superphosphate; 45% superphosphate; superphosphate plus KCl; rock phosphate; manure; manure plus superphosphate; manure plus superphosphate plus KCl; and manure plus rock phosphate on both limed and unlimed plots.

The following conclusions which seem justifiable were drawn from the experimental results of these studies:

1. The total vegetative yield of wheat grown in the greenhouse increased more per unit of available P_2O_5 at the 20 pound rate than with the 40 pound treatment.

2. Addition of phosphorus to the soil decreased the nitrogen percentage of the wheat plants.

3. The uptake of phosphorus by wheat plants on the treated pots was slightly higher than on the untreated pots.

4. Plant composition is somewhat affected by the amounts of nutrients in the soil. Soils which test high in available phosphorus produced plants which contained a higher percentage of phosphorus than those grown on low testing soils.

5. The sodium bicarbonate method was found to give the best correlations of all the tests used on the soils in the greenhouse experiment.

6. The soil test values for available phosphorus on the manure plots tended to give poor correlations with yields, which indicated an effect other than phosphorus from the manure.

7. In the preparation of standards, only slight differences were obtained between standards made up in distilled water and those prepared in the extracting solutions.

8. Correlations on field plots showed promising results for sodium bicarbonate and the Bray 0.1 N HCl extraction methods.

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VITA

Robert Arthur Oppel

Candidate for the Degree of

Master of Science

Thesis: A COMPARISON OF DIFFERENT METHODS FOR DETERMINING AVAILABLE PHOSPHORUS IN SOILS AND THE CORRELATION OF THESE TESTS WITH CROP YIELDS

Major Field: Soils

Biographical and Other Items:

Born: December 12, 1930 at Kingfisher, Oklahoma

Undergraduate Study: Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, 1948-52.

Graduate Study: Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, 1952-54.

Experience: Farm reared; Officer in the United States Army, 1954-56.

Member of Agronomy Club, Gamma Delta, Farm House Fraternity, Officers Club.

Date of Final Examination: May, 1957.