AN EVALUATION OF THREE CHEMICAL EXTRACTANTS FOR THE DETERMINATION OF PHOSPHORUS IN SOILS

by

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INTRODUCTION

Chemical techniques for measuring phosphorus in soils have been used since the mid 1800's. However, these early methods proved to be inadequate in predicting the phosphorus requirements of soils. As soil chemists began to understand the chemistry of phosphorus in soils and the forms of phosphorus that were most readily available, new extractants were proposed that would more closely approximate the phosphorus available for crop utilization.

Several soil test methods are currently used in the United States for predicting available phosphorus. Soil test methods have been consistently modified to regional or state-wide differences in the soils. The only important difference among these methods is the extracting solution. The problem exists in finding a single extractant that is applicable to a variety of soil conditions.

Soils in Kansas range from acidic to calcareous and the Bray P-1 method has been used on all soils to determine available phosphorus. The Bray P-1 method has been an effective test on noncalcareous soils but it has not performed well on some of the calcareous soils of western Kansas. The apparent failure of the method has been due to high amounts of free calcium carbonates present in some western soils. Smith et al (1957) found that a wide soil to solution ratio was necessary when using the Bray P-1 method on calcareous soils from western Kansas.

The Olsen (1954) method is used by several states where their soils are predominately calcareous to determine available phosphorus. However, some people do not like the Olsen method due to technique difficulties involved with the method. Mehlich (1978) has proposed a new extractant that he suggests would be applicable to calcareous and noncalcareous soils. There has been a lot of interest in this new extractant due to the apparent failure of the Bray P-1 method on some calcareous soils and the dislike for the Olsen method.

The study reported in this thesis was undertaken to ascertain the reliability of three chemical soil test methods, Bray P-1 at (1:10) and (1:50) ratios, Olsen, and Mehlich for determining the available phosphorus in Kansas soils and to also add to the general knowledge of this subject.

LITERATURE REVIEW

Numerous extractants have been used to determine available phosphorus in soils. Researchers have tested the various extractants in many correlation studies throughout the United States and in many foreign countries. The literature reviewed and presented in this thesis has been limited primarily to the central region of the United States.

Bray and Kurtz (1945) differentiated the phosphorus forms in the soil into total, organic, and available. The available forms consisted of weak acid-soluble and adsorbed phosphorus. They advocated a method for each phase of soil phosphorus. The extracting solution that received the most attention was the one for adsorbed phosphorus of .03N NH_4F in .025N HCl at a soil solution ratio of 1:7. This adsorbed extracting solution, which will be referred to as Bray P-1 throughout this thesis, is currently used by many states in the north central region and midwest as an extractant for available phosphorus.

Olsen (1954) proposed a $NaHCO_3$ extracting solution, pH 8.5. In reference to earlier studies, he noted that the solubility of the calcium phosphates was shown to be a function of pH and Ca ion activity, with a minimum solubility between the pH 7 to 7.5. He noted that the Bray P-1 worked well on acid and noncalcareous soils, but when free $CaCO_3$ was present the Bray P-1 method yielded consistently low values of extractable phosphorus. The problem was assumed to be due to the

Ca activity and subsequent neutralization of the Bray P-1 extracting solution used on soils high in free $CaCO_3$. The main effect on the $NaHCO_3$ extracting solution on calcareous soils was to decrease the Ca activity, which would increase the solubility of the calcium phosphates.

Olsen compared his $NaHCO_3$ extractant with Bray P-1, water, and carbon dioxide extracts and correlated results to the 'A' value concept. The 'A' value was the numerical figure of the amount of soil phosphorus that is equally available to the plants as that phosphorus added to the soil in a reference fertilizer (Fried 1952). Olsen found a good correlation between the 'A' values and $NaHCO_3$-soluble phosphorus in both acid and calcareous soils. The $NaHCO_3$ method gave the highest correlations with 'A' values with two exceptions out of six experiments - one compared to Bray P-1 and one compared to water soluble methods.

In Nebraska, Olson et al (1954) evaluated five methods for determining available P; Troug, Bray P-1, $NaHCO_3$ and two buffered acetic acid methods used at Nebraska of 10:1 and 1.5:1 dilutions. The 'A' value and yield response were correlated to the available phosphorus as measured by the various methods. They found the Bray P-1 and $NaHCO_3$ methods both acceptable for determining available P in Nebraska soils. No appreciable difference was found between the two methods and both methods gave better results when used on

acid as opposed to calcareous soils. The authors concluded a slight preference for the Bray P-1 method due to technique difficulties involved in the $NaHCO_3$ procedure such as the use of activated charcoal and the effervescence that occurred when the aliquot was neutralized for color development.

Further evaluation in New Mexico by Pack and Gomez (1956) correlated soil test values of four methods with plant analysis. The methods evaluated were carbon dioxide, $NaHCO_3$, Bray P-1, and water. They used plant analysis to correlate to soil test phosphorus instead of the 'A' value because more soils could be evaluated faster and easier. The concentration of phosphorus in cotton leaves and alfalfa forage was correlated to the P extracted from soil samples on which the respective crops were growing. Water soluble soil phosphorus gave the best correlation with concentration of P in both crops. Their results indicated that water extraction was superior to the other three methods tested.

Smith et al (1957) investigated the use of the Bray P-1 and $NaHCO_3$ methods on calcareous soils from western Kansas. Several different acid-fluoride combinations and soil:solution ratios for the Bray P-1 method were tested. The acid-fluoride combination of .03N NH_4F in .025N HCl at a ratio of 1:50 or 1:100 was found to perform better than the original 1:7 ratio on calcareous soils. The 1:100 ratio was not found to significantly improve results over the 1:50 ratio. The

$NaHCO_3$ method worked well, but not as satisfactory as the above mentioned combinations. Rank correlation values between percentage yield values and the phosphorus extracted by various solutions on calcareous soils showed the .03N NH_4F and .025N HCl was higher than all the others with $NaHCO_3$ next. The authors noted the differences between their results and those of Olson (1954) which showed $NaHCO_3$ to be better correlated to plant growth response than the dilute acid-fluoride extraction. Differences were assumed due to the increase in extraction ratio of 1:7 to 1:50 for the acid-fluoride extraction, resulting in the higher correlation values compared to previous studies. At the 1:7 ratio only enough acidity was present to react with .875% $CaCO_3$, so when high amounts of $CaCO_3$ were present, the acid would be expended in dissolving the $CaCO_3$.

On Minnesota soils, Blanchar and Caldwell (1964) evaluated six soil test methods. The methods were the Bray P-1 at 1:10 and 1:50 ratios, $NaHCO_3$, water, Morgan, and exchange resin. They used seven calcareous and seven noncalcareous soils and correlated available P to P uptake by oats. On their study of calcareous soils, all methods except Bray P-1 (1:10), were significantly correlated with plant uptake of P. The water had the highest correlation followed by Bray P-1 (1:50), Morgan, and $NaHCO_3$, respectively. The authors noted that little confidence could be placed in the high correlation

between plant uptake and water-soluble P since it was obtained from only 2 detectable measurements and 5 trace values. The use of the wider soil to solution ratio with the Bray P-1 extracting solution significantly improved the correlation of plant uptake P and P determined by the Bray P-1 extractant, which confirmed the earlier results of Smith et al (1957). They also stated that with soils containing calcium carbonates the Bray P-1 extracting solution was rapidly neutralized by the carbonate rather than utilized in the dissolution of calcium phosphates.

On noncalcareous soils all methods were significantly correlated to P uptake. The highest correlation to P uptake was with Morgan, water, Bray P-1(1:10), $NaHCO_3$, and Bray P-1 (1:50) following in respective order. The Bray P-1(1:10) ratio worked very well on noncalcareous soils but was not satisfactory at all on the calcareous soils.

Laverty (1964) proposed a modified procedure for the determination of P in soil extracts, applicable to the Bray P-1 extracting solution. The reason he modified Kurtz and Arnold's (1946) procedure was to increase the stability of the blue color formed when the reducing agent was added. Laverty's procedure is presently used in the color development with the Bray P-1 method.

Olsen and Watanabe (1965) evaluated a proposed procedure by Murphy and Riley (1962) of a single reagent for determining

phosphorus in water and $NaHCO_3$ extracts from soil. They found no significant difference between the new procedure and the one first used by Dickman and Bray (1946). They observed several desirable traits with the Murphy and Riley method such as elimination of the use of carbon black and the fast color development and stability of the blue color developed. Murphy and Riley's ascorbic acid method is presently used in association with $NaHCO_3$ extracts for color development.

Randall and Grava (1971) conducted a field study to determine extractable P variability on highly fertilized calcareous Minnesota soils using the Bray P-1 extracting solution at three different ratios (1:10, 1:50, and 1:100). They found a decreasing curvilinear relationship between the extractable P at all three soil to solution ratios and the calcium carbonate equivalence. The soils containing primarily calcitic carbonates were found to have the capacity of neutralizing more acid than the soil containing dolomitic carbonates. They also postulated the formation of CaF_2 occurred during the extraction process which would deactivate the fluoride ion. The subsequent neutralization of the dilute acid and the deactivation of the fluoride ion by the calcium in highly calcareous soils resulted in the repressing effect of the calcium carbonates on the extraction of phosphorus by the Bray P-1 extractant. The formation of

CaF_2 was confirmed by Smillie and Syers (1972) during a one minute extraction of calcite with the Bray P-1 reagent.

Mehlich (1978) found that the precipitation of CaF_2 was not only found in calcareous soils, but may also occur in neutral and acid soils. Mehlich was working on an extractant that would simultaneously extract several nutrients. He showed that the advantages of the fluoride ion, when added to .025N HCl to control selective extractability of P, did not apply simultaneously to Ca unless the pH of the extractant was held below about pH 2.9. In order to achieve this in calcareous soils either a wide soil to solution ratio or a considerable higher buffer capacity than is inherent in Bray P-1 was required. Mehlich proposed a new extractant that would offer the desirable buffer properties for the simultaneous extraction of P and Ca from rock phosphate and soils.

The extractant was 0.2N NH_4Cl-0.2N HOAc-0.015N NH_4F-0.012N HCl at approximately a pH of 2.5. Mehlich compared his new extractant to Bray P-1(1:10), $NaHCO_3$, and Mehlich double acid (DA) for extractable P. Phosphorus uptake by millet was correlated to the extracted P by the various methods. The rank correlations of all soils was highest with DA, followed by the new extractant, Bray P-1, and Olsen. The soils that he tested did not include calcareous soils which require the higher soil:solution ratios of 1:50 or 1:100 as

found by Smith et al (1957), Randall and Grava (1971), and Smillie and Syers (1972).

The available phosphorus in soils has been correlated to many factors, such as, the P uptake and %P of different crops, the 'A' value concept, and yield response. Among the methods investigated, the Bray P-1 and Olsen have been shown to be superior methods in many studies. With the recent introduction of the new extractant by Mehlich, there is an apparent need to evaluate the methods to establish which method would be most suitable for the soil conditions common in Kansas.

MATERIALS AND METHODS

Source and Preparation of Soil Samples

Surface bulk soil samples (0-15cm) of 40 soils were collected from various locations throughout the state of Kansas. (Appendix, Table 1) The majority of the soils were selected from phosphorus responsive sites where known phosphorus rates have been applied for many years. Soils were selected to give a range in factors such as pH, free calcium carbonate, and fertility levels.

The soils were air dried and screened through a 10 mm screen to remove large particles. Three replicates of each soil were used for the growth chamber study, with 750 g of soil in each pot. Another 100 g of soil was retained for chemical analyses of each soil. The 100 g from each soil was dried, crushed with a power driven mortar and pestle, and screened through a 2 mm screen.

Soil Analysis

The soil samples were analyzed for pH, lime requirement, organic matter, free calcium carbonate, DTPA Fe and Zn, and available P. All tests were done on a weight basis.

The pH was determined on a 1:1 soil to water ratio and the lime requirement was determined by the Shoemaker-McLean-Pratt (SMP) buffer system by procedures of McLean (1975). The organic matter was determined colorimetrically by the

procedure of Graham (1948). The DTPA Fe and Zn were determined according to the procedure of Lindsay and Norvell (1978).

The free calcium carbonate percent was determined with a sealed apparatus designed to measure volume displacement of water due to evolution of carbon dioxide when soil samples are treated with HCl. A 1 g sample of pure calcium carbonate was treated with HCl and used as a standard reference for the soil samples.

Phosphorus Methods

The soil samples were analyzed by the Bray P-1 at a 1:10 and 1:50 soil to solution ratio, Olsen, and the new method proposed by Mehlich (1978). The Bray P-1 and Olsen methods were run according to the procedure of Knudsen (1975) with only slight modifications to the Bray P-1 procedure. The modifications consisted of a 40 second shaking period compared to the 5 minutes that Knudsen called for and the use of 125 ml Erlenmeyer flasks being shaken on a wrist action shaker when the Bray P-1 method was run on a 1:50 soil to solution ratio. The soil extracts were read on a Baush and Lomb Spectronic 20.

Bray Method

Reagents:

1. Extracting solution: (.025 N HCl in .03N NH_4F)

Dissolve 11.11 g of reagent grade ammonium flouride in about

9 liters of distilled water. Add 21.6 ml of concentrated HCl and make to 10 liter volume with distilled water, and mix throughly. The pH should be 2.6 $\pm$ .05. Store in polyethlylene.

2. Acid molybdate stock solution (P-B solution). Dissolve 75.25 g of ammonium molybdate in 500 ml of distilled water heated to 60°C. Cool the solution and mix with 1500 ml HCl. Dilute the solution to 2000 ml with distilled water in a volumetric flask and store in a glass stoppered brown bottle to which 100 g of boric acid has been added.

3. Dry reducing agent: Aminonaphthol-sulfonic acid (P-C powder). Mix 5 g of 1-amino-2-naphthol-4-sulfonic acid with 10 g of sodium sulfite and 292.5 g of sodium pyrosulfite. Grind the mixture to a fine powder.

4. Dilute reducing agent (P-C solution). Dissolve 16 g of dry reducing agent in 100 ml of distilled water heated to 60°C. Cool and store in a brown bottle.

Procedure:

1. Weigh 1 g of soil and place in 50 ml Erlenmeyer flask. Add 10 ml of extracting solution to each flask and shake at 200 opm for 40 seconds. Filter extracts through Whatman No. 2 filter paper into air vented funnel tubes.

1a. (Optional step applicable at 1:50 ratio.) Weigh 1 g of soil and place in 125 ml Erlenmeyer flask. Add 50 ml of extracting solution to each flask and shake for 40 seconds

on a wrist action shaker. Filter extracts through Whatman No. 2 filter paper into air vented funnel tubes.

2. Transfer a 5 ml aliquot to a test tube or cuvette.

3. Add .25 ml of P-B solution, shake, and add .25 ml of P-C solution. Allow color to develop 15 minutes before reading the samples.

4. Set wavelength at 660 nm on the Baush and Lomb Spectronic 20, set zero %T on the scale and insert blank containing extracting solution to set 100 %T. Insert samples and read absorbance within 45 minutes after adding the reducing agent.

5. Prepare a standard curve by pipetting 5 ml aliquots of known phosphorus standards, 0 to 10 ppm P, and develop color and read absorbance in the same manner as with the soil extracts. By reference to this curve ppm P in the soil may be determined.

Olsen Method

Reagents:

1. Extracting solution: (.5N $NaHCO_3$, pH 8.5) Dissolve 420 g of commercial grade sodium bicarbonate in distilled water and make to a volume of 10 liters. Adjust to pH 8.5 with 50% sodium hydroxide.

2. Acid molybdate stock solution (Reagent A). Dissolve 60 g of ammonium molybdate in 1250 ml of distilled water. Dissolve 1.455 g of antimony potassium tartrate in 500 ml of

distilled water. Add both of these solutions to 5000 ml of 5N H_2SO_4, mix and dilute to 10 liters with distilled water. Store in pyrex glass bottle in a dark cool place.

3. Reagent B. Dissolve 2.639 g of ascorbic acid in 500 ml of reagent A. Prepare this reagent daily.

Procedure:

1. Weigh 1 g of soil and place in 50 ml Erlenmeyer flask. Add 20 ml of extracting solution to each flask and shake at 200 opm for 30 minutes. Filter extracts through Whatman No. 2 filter paper.

2. Transfer a 5 ml aliquot to a 25 ml volumetric flask.

3. Add 15 ml of distilled water and bring up to volume with reagent B. Agitate so thorough mixing occurs. (Caution should be used when reagent B is added due to the possible loss of liquid from rapid evolution of carbon dioxide.) Allow color to develop for 10 minutes before reading the samples.

4. Set wavelength at 882 nm on the Baush and Lomb Spectronic 20, set zero %T on the scale and insert blank containing extracting solution to set 100 %T. Transfer samples to cuvettes and insert samples into the instrument and read absorbance.

5. Prepare a standard curve by pipetting a 5 ml aliquot of known phosphorus standards, 0 to 5 ppm P, and develop color and read absorbance in the same manner as with the soil extracts. By reference to this curve ppm P in the soil may be determined.

Mehlich Method

Reagents:

1. Extracting solution: (.2N NH_4Cl-.2N HOAc-.015N NH_4F-.012N HCl, pH 2.5) Dissolve 5.6 g ammonium flouride and 107 g ammonium chloride in about 5 liters distilled water, add 10 ml HCl, 115 ml of glacial acetic acid and make to 10 liters with distilled water.

2. Sulfuric-Molybdate-Tartrate Solution. Dissolve 100 g ammonium molybdate and 2.425 g antimony in 500 ml water (heat if needed, but don't exceed 60°C). Slowly add 1400 ml concentrated sulfuric acid and mix well. Let cool and dilute to 2 liters with distilled water. Store in polyethylene or pyrex bottle in dark, refrigerated compartment.

3. Ascorbic Acid Solution. Dissolve 88.0 g ascorbic acid in distilled water and dilute to 1 liter with water. Store in dark glass bottle in a refrigerated compartment.

4. Working Solution. For a 10 liter quantity add to about 5000 ml of water, 200 ml of molybdate solution, and 100 ml of ascorbic acid solution. Make to volume with water and mix. Prepare fresh after 3 days. Allow to stand about one-half hour or until room temperature is reached before using.

Procedure:

1. Weigh 1 g of soil and place in 50 ml Erlenmeyer

flask. Add 10 ml of extracting solution to each flask and shake at 200 opm for 5 minutes. Filter extracts through Whatman No. 2 filter paper.

2. Transfer a 2 ml aliquot into a 25 ml volumetric flask and bring to a volume with working solution. Allow 15 minutes for color development.

3. Set wavelength at 882 nm on the Baush and Lomb Spectronic 20, set zero %T on the scale and insert blank containing extracting solution to set 100 %T. Transfer samples to cuvettes and insert samples into the instrument and read absorbance.

4. Prepare a standard curve by pipetting a 2 ml aliquot of known phosphorus standards, 0 to 10 ppm P, and develop color and read absorbance in the same manner as with the soil extracts. By reference to this curve ppm P in the soil may be determined.

Growth Chamber

A growth chamber study was initiated to determine the availability of P in the 40 soils. The soils used in this study were selected in an attempt to have a wide range in pH, free calcium carbonates, and fertility status. There was no phosphorus added to any of the soils due to selection of samples from phosphorus responsive and nonresponsive sites where known phosphorus rates have been applied for many years. Three replicates of each soil were distributed in a randomized complete block design with 750 g of soil per pot.

Growth chamber conditions were 16 and 8 hours of light and dark at 85°F and 65°F, respectively. The lighting was provided by sixteen 160-watt flourescent lamps and six 300-watt incandescent lamps. Distilled water was applied daily as required and plants were rotated daily within replications to eliminate position effect in the chamber.

Two separate corn (Zea mays L.) crops were grown using the same pot of soil. Six kernels of 'Bojac X56' corn were planted per pot. Plants were thinned to 3 per pot one week after emergence. During the first corn crop, 100 ppm N, 100 ppm K, and 5 ppm Fe were added to each pot through watering. Plants were clipped at the soil surface and harvested 21 days after emergence on the first crop. The plants were dried in a forced air dryer for 72 hours at 50°C and then weighed. The

tissue was then ground through a UD cyclone sample mill and stored in plastic containers for later analysis.

The second crop was planted in the same pots without remixing the soil and treated as the first planting. Old plant roots were left in the soil and an additional 100 ppm N, 100 ppm K, and 5 ppm Zn were added to the pots. The second crop was harvested 20 days after emergence and crop tissue was treated in the same manner as outlined under crop one.

Phosphorus analysis of the tissue was done on a sulfuric acid digestion, Linder and Harley (1942). A 0.25 g sample was weighed into a digestion tube and 2 ml of concentrated sulfuric acid was added. The samples were placed under a hood and 1 ml of 30% H_2O_2 was added. The tubes were placed in aluminum digestion blocks and heated to 375°C for approximately 45 minutes. The samples were then removed from the blocks and allowed to cool about 15 minutes. An additional 1 ml of H_2O_2 was added and the samples heated again. This procedure was repeated until the solution remained clear. The digestion tubes were then removed from the blocks and allowed to cool. The samples were diluted to 50 ml with distilled deionized water and stored in polyethylene bottles. The phosphorus in the samples was determined colorimetrically by a vanadate-molybdate method, wavelength 660 nm, using the Technicon Auto Analyzer (1977).

Statistical Analysis

The data collected was analyzed statistically at the KSU Computing Center using the Statistical Analysis System (SAS). Analysis of variance of data was tested at the 5% level of significance. Linear correlations were determined between the amount of phosphorus extracted by the various methods and the mean tissue weight, %P, and P uptake of the three replicates per soil for both crops, separately, and to the combined total P uptake of both corn crops as presented in Appendix Table 4. Significant difference among the correlation coefficients for the various methods was tested by use of Fisher's z transformation of the correlation coefficients (Snedecor and Cochran, 1967).

RESULTS AND DISCUSSION

The forty soil samples used in this study consisted of fifteen calcareous and twenty-five noncalcareous soils. The soil test data including the available P as determined by the various P extraction methods are presented in Appendix Tables 2 and 3, respectively. The soils had a wide range in pH, organic matter, free calcium carbonates, and fertility status. In reference to the current soil test levels for the Bray P-1 (1:10) method used at the KSU Soil Testing Laboratory (Whitney 1976), the soils in this study would fall in all 5 interpretation levels presently used to make phosphorus recommendations. There were seven soils very low(0-5ppm P), eight soils low (5-12ppm P), fourteen soils medium(12-25ppm P), seven soils high(25-50ppm P), and four soils very high(50 or more ppm P). These soils represent the range in phosphorus status of soils in Kansas and many of the major soil types.

The tissue weight, %P, and P uptake of the corn crops are presented in Appendix Tables 5-10. The mean values of the three replications and the total P uptake for both crops are presented in Appendix Table 4. Significant difference among soils in phosphorus uptake was found. The second crop had consistently higher P uptake compared to the first crop. The higher P uptake and dry matter yields in Crop 2 reflect better plant growth possibly due to response to the added Zn.

Treatments imposed on the land prior to collection of the soil samples resulted in considerable variation in mean %P in the corn plants. For example, soils 3 and 4 from Colby had prior treatments of 75-0-0 and 75-90-0, respectively. The mean %P of corn plants grown on soil 3 had a range of .14 to .15 while the corn plants grown on soil 4 ranged from .23 to .29 %P which shows the good phosphorus response to residual phosphorus fertilizer. The total P uptake over both crops also reflected this difference in that soil 3 had 5.76 mg/pot and soil 4 had almost double that amount with 11.19 mg/pot. Many of the other soils from the phosphorus responsive sites had much the same trend in the %P and P uptake.

The phosphorus uptake by both crops, separately, and the total uptake of the two crops was correlated to the extractable P by the various phosphorus soil test methods and is presented in Table 1. The Bray P-1(1:10) and the Olsen methods both had higher correlations to P uptake than the Mehlich or Bray P-1(1:50) on individual corn crops and total P uptake. The Bray P-1(1:10) was highest on Crop 1 and total P uptake while the Olsen was highest on Crop 2. All methods were significantly correlated to P uptake at the 1% level and a test of correlation coefficients showed no significant difference among the correlation coefficents for the methods.

The data was divided into calcareous and noncalcareous soils to evaluate the P methods on the respective soil conditions. The free calcium carbonate percent in the soils range from 1.5% to 48.1% and the pH of the soils with free calcium carbonates ranged from 7.6 to 8.0. There were several soils that had a pH of 7.6, or very close to 7.6, that did not have any free calcium carbonates. Therefore, only the presence of measurable free calcium carbonates was used as the criterion for the separation of soils into the calcareous and noncalcareous groups.

The correlation coefficients on calcareous soils are presented in Table 2. The methods followed the same trend in all correlations over both crops and to combined total uptake. The Olsen, Mehlich, and Bray P-1(1:50) were correlated to P uptake at the 1% significance level on individual corn crops and combined total P uptake, while the Bray P-1(1:10) was significant at the 5% level. The Olsen method had the highest correlation followed by Mehlich, Bray P-1(1:50), and Bray P-1(1:10), respectively. A test of correlation coefficients showed there was no significant difference among the correlation coefficients for the methods. However, more confidence may be placed in the Olsen, Mehlich, and Bray P-1 (1:50) due to significance at the 1% level compared to the 5% level of significance for the Bray P-1(1:10).

Table 1. Correlation coefficients between plant uptake of P and available P in all forty soils.

P Uptake vs.	Correlation Coefficients (r)		
	Crop 1	Crop 2	Total Uptake
Bray P-1(1:10)	.872**	.757**	.832**
Bray P-1(1:50)	.786**	.735**	.778**
Olsen	.833**	.775**	.822**
Mehlich	.757**	.739**	.765**

**Significant at 1% level.

Table 2. Correlation coefficients between plant uptake of P and available P in fifteen calcareous soils.

P Uptake vs.	Correlation Coefficients (r)		
	Crop 1	Crop 2	Total Uptake
Bray P-1(1:10)	.593*	.526*	.581*
Bray P-1(1:50)	.629**	.620**	.657**
Olsen	.702**	.697**	.737**
Mehlich	.654**	.681**	.708**

* Significant at 5% level.
**Significant at 1% level.

The correlation coefficients on noncalcareous soils are presented in Table 3. The Mehlich and Olsen methods were again found to have the highest correlation on both crops and total P uptake. The Mehlich method had the highest correlation with the Olsen second highest. The Bray P-1(1:50) was higher than the Bray P-1(1:10) on Crop 2 and total uptake. All methods were significantly correlated at the 1% level and a test of correlation coefficients showed no significant difference among the correlation coefficients for the methods.

Correlations between the amount of P extracted by the various methods are presented in Table 4. The methods were correlated on calcareous, noncalcareous, and the combined forty soils. All methods were found to be significantly correlated at the 1% level on the noncalcareous soils and the combined forty soils. On the calcareous soils all the methods with the exception of Bray P-1(1:10) vs. Olsen or Mehlich were significantly correlated.

The mean values for %P and tissue weights presented in Appendix Table 4 were correlated to the extractable P by the various phosphorus soil test methods and are presented in Table 5. The data were also divided into calcareous and noncalcareous soils and are presented in Table 6 and 7, respectively. The correlations for %P were found to be higher than the correlations for tissue weight. The correlations would indicate that %P would be the better factor in

Table 3. Correlation coefficients between plant uptake of P and available P in twenty-five noncalcareous soils.

P Uptake vs.	Correlation Coefficients (r)		
	Crop 1	Crop 2	Total Uptake
Bray P-1(1:10)	.876**	.785**	.843**
Bray P-1(1:50)	.887**	.783**	.847**
Olsen	.901**	.797**	.861**
Mehlich	.909**	.810**	.872**

**Significant at 1% level.

Table 4. Correlation coefficients between the various methods.

Factors Correlated	Correlation Coefficients (r)		
	C[1]	NC[2]	Overall
Bray P-1(1:10) vs. Olsen	.440	.990**	.870**
Bray P-1(1:50) vs. Olsen	.892**	.991**	.961**
Bray P-1(1:10) vs. Mehlich	.473	.993**	.792**
Bray P-1(1:50) vs. Mehlich	.969**	.992**	.974**
Bray P-1 (1:10) vs. (1:50)	.604*	.993**	.861**
Olsen vs. Mehlich	.958**	.993**	.964**

[1]C represents fifteen calcareous soils.
[2]NC represents twenty-five noncalcareous soils.
* Significant at 5% level.
**Significant at 1% level.

Table 5. Correlation coefficients between available P in all forty soils and the %P and tissue weights.

Extraction Procedure	Correlation Coefficients (r)			
	Crop 1		Crop 2	
	%P	Tiss.Wt.	%P	Tiss.Wt.
Bray P-1(1:10)	.832**	.696**	.661**	.574**
Bray P-1(1:50)	.777**	.604**	.691**	.514**
Olsen	.806**	.661**	.730**	.532**
Mehlich	.759**	.555**	.717**	.491**

**Significant at 1% level.

Table 6. Correlation coefficients between available P in fifteen calcareous soils and the %P and tissue weights.

Extraction Procedure	Correlation Coefficients (r)			
	Crop 1		Crop 2	
	%P	Tiss.Wt.	%P	Tiss.Wt.
Bray P-1(1:10)	.643**	.249	.366	.420
Bray P-1(1:50)	.618**	.274	.653**	.291
Olsen	.512*	.486	.654**	.403
Mehlich	.569*	.358	.698**	.347

* Significant at 5% level.
**Significant at 1% level.

Table 7. Correlation coefficients between available P in twenty-five noncalcareous soils and the %P and tissue weights.

Extraction Procedure	Correlation Coefficients (r)			
	Crop 1		Crop 2	
	%P	Tiss.Wt.	%P	Tiss.Wt.
Bray P-1(1:10)	.842**	.761**	.721**	.623**
Bray P-1(1:50)	.854**	.774**	.718**	.628**
Olsen	.882**	.745**	.756**	.584**
Mehlich	.885**	.757**	.751**	.622**

**Significant at 1% level.

determining the linear relationship with extractable P by the various methods.

The correlations obtained for %P and P uptake were compared and the %P correlations were consistently lower and did not have the specific trend over both corn crops as did the correlations to P uptake. Of the three plant factors, P uptake, %P, and tissue weight, correlated to the extractable P by the various methods, the correlations for P uptake were overall highest and more consistent from Crop 1 to Crop 2. The P uptake by corn plants would be the superior factor for correlations to the available phosphorus.

CONCLUSIONS

Soils used in this investigation were representative of the wide variation in soil conditions and fertility status found in Kansas soils. The results of the correlation studies show no definite superiority of any one method in predicting available phosphorus. The highest correlation coefficients were obtained on the noncalcareous soils, indicating that all three methods may be more applicable for use on noncalcareous soils as opposed to calcareous soils or a combination of the soil conditions.

The problem associated with the different methods has not been on the noncalcareous soils. The problem has been on predominately calcareous soils. More confidence may be placed in the Olsen, Mehlich, and Bray P-1(1:50) than the Bray P-1(1:10) when used on calcareous soils. Our results confirmed the reports of other studies that the increase of the soil to solution ratio with the Bray P-1 method on calcareous soils would improve the correlations, but the differences were not found to be a significant improvement.

Correlations were determined between the amount of phosphorus extracted by the various P extraction methods to three plant growth factors, P uptake, %P, and tissue weight. Of the plant factors correlated to the extracted P by the various methods, the correlations for P uptake were overall highest and had a more consistent trend from Crop 1 to Crop 2.

The P uptake by corn plants would be superior for correlation to the available phosphorus in the soils.

In conclusion, due to the lack of finding a significant difference among the methods evaluated there would not be substantial reason to change from the Bray P-1(1:10) method presently used in the Kansas State University Soil Testing Laboratory. However, on very calcareous soils, those interpreting soil tests must recognize the weakness of the P extraction methods.

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APPENDIX

Table 1. Source of soil samples and treatments prior to collection of samples.

Sample #	Source	Treatment
1.	Ashland	0-0-0
2.	Ashland	0-80-0
3.	Colby	75-0-0
4.	Colby	75-90-0
5.	Columbus (Rotation)	Lime, No-P
6.	Columbus (Rotation)	L,P,K
7.	Decatur County	Unknown-Colby Soil
8.	Garden City (IP)*	180-0-0
9.	Garden City (IP)*	180-40-0
10.	Garden City (IP)*	180-80-40
11.	Garden City (ES)**	0-P_2O_5
12.	Garden City (ES)**	40-P_2O_5-3Yrs.
13.	Garden City (ES)**	80-P_2O_5-3Yrs.
14.	Gove County	Unknown
15.	Hutchinson	75-0-0
16.	Hutchinson	75-40-0
17.	Kansas River Valley	300-0-0
18.	Kansas River Valley	300-60-0
19.	Ness County	Unknown
20.	Ottawa	P-Residual Check

*IP - Represents Irrigation Project
**ES - Represents Experimental Station

Table 1. (Cont'd) Source of soil samples and treatments prior to collection of samples.

Sample #	Source	Treatment
21.	Ottawa	P-Residual 200#'s 74&78
22.	Parsons	No-P
23.	Parsons	200#'s A.P.P.
24.	Powhattan	Unknown
25.	Scandia	225-0-0
26.	Scandia	225-100-0
27.	Servi Tech	30 Tons Manure
28.	Servi Tech	20 Tons Manure
29.	Servi Tech	110-50-0,25#'s $ZnSO_4$(18%)
30.	Servi Tech	55-40-0
31.	Servi Tech	110-0-0
32.	Servi Tech	15-40-0
33.	Servi Tech	175-40-0,20#'s $ZnSO_4$
34.	St. John	225-0-0
35.	St. John	225-50-0
36.	Tribune (Long Term)	0-0-0
37.	Tribune (Long Term)	160-40-0
38.	Tribune (Residual '74)	160-40-0
39.	Wichita	50-30-0
40.	Wichita	75-30-0

Table 2. Soil test data on the forty soils used in the greenhouse study.

Sample #	pH	Lime Req. (ECC)	O.M. (%)	Free $CaCO_3$ (%)	DTPA Zinc (ppm)	DTPA Iron (ppm)
1.	6.2	2500	2.1	--	.98	67.55
2.	6.3	2500	1.9	--	.86	55.69
3.	7.5	--	1.7	--	.50	3.34
4.	7.6	--	1.6	--	.42	4.05
5.	6.8	--	1.2	--	2.72	19.73
6.	7.0	--	1.5	--	2.81	24.14
7.	7.9	--	0.9	6.3	.18	2.48
8.	7.8	--	1.6	1.9	.76	4.49
9.	7.8	--	1.4	1.9	.62	3.87
10.	7.6	--	1.6	1.5	.72	4.66
11.	8.0	--	1.3	5.4	.32	3.21
12.	8.0	--	1.6	4.6	.42	3.21
13.	8.0	--	1.3	6.2	.42	3.25
14.	6.6	--	1.2	--	.28	16.70
15.	5.9	3000	2.1	--	.45	41.74
16.	6.1	2000	2.2	--	.58	35.45
17.	7.1	--	1.2	--	1.39	17.30
18.	6.2	1000	1.1	--	1.51	34.55
19.	6.6	--	1.6	--	.27	11.89
20.	5.3	6000	3.4	--	1.60	107.05

Table 2. (Cont'd) Soil test data on the forty soils used in the greenhouse study.

Sample #	pH	Lime Req. (ECC)	O.M. (%)	Free $CaCO_3$ (%)	DTPA Zinc (ppm)	DTPA Iron (ppm)
21.	5.2	5000	3.5	--	1.55	98.20
22.	5.6	2500	2.6	--	1.19	53.01
23.	5.6	2500	2.7	--	1.22	57.45
24.	5.3	7500	3.8	--	1.87	164.85
25.	6.6	--	2.4	--	.45	40.87
26.	6.5	--	2.2	--	.50	48.54
27.	7.7	--	1.3	48.1	.27	3.31
28.	7.9	--	1.1	3.1	2.82	3.19
29.	7.1	--	1.4	--	.48	8.31
30.	8.0	--	1.4	4.6	.27	4.10
31.	7.9	--	2.5	3.5	4.34	8.51
32.	7.8	--	1.7	5.8	1.01	2.64
33.	7.1	--	2.0	--	.96	10.80
34.	5.8	1000	0.7	--	1.52	24.61
35.	5.4	1500	1.1	--	2.11	30.33
36.	7.8	--	1.5	3.9	1.06	2.74
37.	7.9	--	1.6	1.5	1.13	3.04
38.	7.9	--	1.6	2.3	1.10	3.05
39.	5.6	4000	2.0	--	.96	48.91
40.	5.9	3000	2.2	--	1.02	56.35

Table 3. Available phosphorus values for the various methods.

Sample #	Available P (ppm)			
	Bray P-1 (1:10)	Bray P-1 (1:10)	Olsen	Mehlich
1.	89	130	49	95
2.	72	103	40	68
3.	17	32	9	21
4.	75	119	51	87
5.	5	11	3	6
6.	10	26	9	12
7.	6	16	4	12
8.	8	20	3	12
9.	15	30	7	20
10.	20	40	9	25
11.	2	28	6	22
12.	15	63	18	49
13.	7	49	16	47
14.	16	30	8	19
15.	5	16	2	7
16.	5	13	3	8
17.	16	34	9	19
18.	42	61	25	45
19.	13	26	6	13
20.	10	20	6	10

Table 3. (Cont'd) Available phosphorus values for the various methods.

Sample #	Available P (ppm)			
	Bray P-1 (1:10)	Bray P-1 (1:50)	Olsen	Mehlich
21.	26	47	15	28
22.	6	18	4	6
23.	30	57	20	31
24.	17	36	10	18
25.	39	61	22	36
26.	79	107	46	77
27.	2	1	16	18
28.	22	34	12	27
29.	17	36	9	18
30.	9	20	5	12
31.	26	136	51	108
32.	3	36	9	32
33.	11	18	6	12
34.	4	9	1	4
35.	15	30	9	16
36.	25	51	13	35
37.	22	40	10	28
38.	18	34	7	24
39.	37	59	18	34
40.	32	55	18	31

Table 4. Total P uptake and mean values for tissue weight, %P, and P uptake for corn crops 1 and 2.

Sample #	Crop 1			Crop 2			Total P Uptake (mg)
	Tissue Wt.(gm)	%P (plant)	P Uptake (mg/pot)	Tissue Wt.(gm)	%P (plant)	P Uptake (mg/pot)	
1.	2.08	0.23	4.73	2.61	0.18	4.78	9.51
2.	2.00	0.20	4.06	2.41	0.19	4.68	8.74
3.	1.57	0.14	2.17	2.39	0.15	3.59	5.76
4.	1.96	0.29	5.78	2.34	0.23	5.41	11.19
5.	1.24	0.12	1.51	1.47	0.11	1.62	3.13
6.	1.43	0.12	1.75	1.68	0.13	2.14	3.89
7.	1.39	0.10	1.44	1.76	0.10	1.81	3.25
8.	0.97	0.12	1.19	1.23	0.12	1.48	2.67
9.	1.03	0.12	1.19	1.55	0.15	2.34	3.53
10.	1.13	0.12	1.32	1.61	0.15	2.49	3.81
11.	1.28	0.12	1.52	1.55	0.13	1.94	3.46
12.	1.57	0.13	1.99	1.95	0.15	3.02	5.01
13.	1.26	0.13	1.58	1.72	0.18	3.00	4.58
14.	1.80	0.13	2.26	2.62	0.14	3.60	5.86

Table 4. (Cont'd) Total P uptake and mean values for tissue weight, %P, and P uptake for corn crops 1 and 2.

Sample #	Crop 1			Crop 2			Total P Uptake (mg)
	Tissue Wt.(gm)	%P (plant)	P Uptake (mg/pot)	Tissue Wt.(gm)	%P (plant)	P Uptake (mg/pot)	
15.	1.31	0.10	1.31	1.59	0.10	1.64	2.95
16.	1.31	0.10	1.31	1.70	0.11	1.81	3.12
17.	1.86	0.14	2.54	2.12	0.16	3.47	6.01
18.	2.09	0.22	4.55	2.30	0.26	5.85	10.40
19.	1.74	0.12	2.07	2.34	0.13	3.04	5.11
20.	1.24	0.11	1.36	1.70	0.11	1.88	3.24
21.	1.51	0.13	1.92	1.81	0.12	2.18	4.10
22.	1.20	0.10	1.24	1.51	0.10	1.62	2.86
23.	1.74	0.15	2.54	1.99	0.16	3.28	5.82
24.	1.43	0.12	1.71	1.73	0.11	1.95	3.66
25.	1.79	0.13	2.38	2.16	0.14	3.11	5.49
26.	1.90	0.18	3.41	2.32	0.18	4.26	7.67
27.	1.74	0.11	1.97	2.31	0.13	3.06	5.03
28.	1.51	0.11	1.67	1.61	0.13	2.07	3.74

Table 4. (Cont'd) Total P uptake and mean values for tissue weight, %P, and P uptake for corn crops 1 and 2.

Sample #	Crop 1			Crop 2			Total P Uptake (mg)
	Tissue Wt.(gm)	%P (plant)	P Uptake (mg/pot)	Tissue Wt.(gm)	%P (plant)	P Uptake (mg/pot)	
29.	1.69	0.13	2.15	2.50	0.11	2.86	5.01
30.	1.56	0.10	1.56	1.54	0.10	1.61	3.17
31.	1.70	0.15	2.60	2.18	0.18	3.85	6.45
32.	1.14	0.11	1.29	1.75	0.11	2.03	3.32
33.	1.51	0.11	1.65	2.01	0.12	2.50	4.15
34.	1.12	0.11	1.23	1.61	0.10	1.55	2.78
35.	1.73	0.10	1.84	1.95	0.13	2.60	4.44
36.	1.53	0.16	2.42	2.35	0.13	2.99	5.41
37.	1.32	0.16	2.05	2.50	0.15	3.69	5.74
38.	1.65	0.11	1.87	2.26	0.12	2.64	4.51
39.	1.70	0.11	1.94	2.14	0.10	2.22	4.16
40.	1.98	0.12	2.38	2.42	0.10	2.61	4.99

Table 5. Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 1, Rep A).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
1.	2.21	0.22	4.86
2.	2.24	0.20	4.48
3.	1.58	0.12	1.90
4.	1.87	0.29	5.42
5.	1.03	0.14	1.44
6.	1.57	0.12	1.88
7.	1.25	0.10	1.25
8.	1.02	0.11	1.12
9.	0.88	0.13	1.14
10.	1.10	0.11	1.21
11.	1.24	0.11	1.36
12.	1.62	0.13	2.11
13.	1.34	0.12	1.61
14.	1.70	0.12	2.04
15.	1.28	0.10	1.28
16.	1.44	0.10	1.44
17.	1.83	0.13	2.38
18.	2.13	0.22	4.69
19.	1.74	0.12	2.09
20.	1.36	0.12	1.63

Table 5. (Cont'd) Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 1, Rep A).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
21.	1.69	0.12	2.03
22.	1.15	0.10	1.15
23.	1.96	0.13	2.55
24.	1.50	0.11	1.65
25.	1.77	0.13	2.30
26.	1.91	0.17	3.25
27.	1.82	0.11	2.00
28.	1.65	0.11	1.82
29.	1.68	0.12	2.02
30.	1.74	0.10	1.74
31.	1.69	0.14	2.37
32.	1.12	0.11	1.23
33.	1.42	0.13	1.85
34.	1.06	0.11	1.17
35.	1.88	0.10	1.88
36.	1.76	0.14	2.46
37.	1.47	0.14	2.06
38.	1.88	0.10	1.88
39.	1.82	0.12	2.18
40.	1.78	0.12	2.14

Table 6. Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 1, Rep B).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
1.	2.13	0.26	5.54
2.	1.94	0.21	4.07
3.	1.76	0.16	2.82
4.	2.13	0.32	6.82
5.	1.56	0.11	1.72
6.	1.27	0.14	1.78
7.	1.76	0.10	1.76
8.	0.97	0.13	1.26
9.	1.04	0.11	1.14
10.	1.13	0.12	1.36
11.	1.55	0.13	2.02
12.	1.54	0.13	2.00
13.	1.07	0.14	1.50
14.	2.06	0.12	2.47
15.	1.42	0.10	1.42
16.	1.23	0.10	1.23
17.	1.88	0.15	2.82
18.	2.25	0.24	5.40
19.	2.06	0.11	2.27
20.	1.43	0.10	1.43

Table 6. (Cont'd) Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 1, Rep B).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
21.	1.61	0.14	2.25
22.	1.34	0.10	1.34
23.	1.65	0.16	2.64
24.	1.29	0.13	1.68
25.	1.97	0.13	2.56
26.	2.11	0.18	3.80
27.	1.68	0.12	2.02
28.	1.46	0.11	1.61
29.	1.83	0.14	2.56
30.	1.52	0.09	1.37
31.	1.62	0.18	2.92
32.	0.96	0.12	1.15
33.	1.59	0.10	1.59
34.	1.12	0.12	1.34
35.	1.58	0.12	1.90
36.	1.52	0.17	2.58
37.	1.12	0.18	2.02
38.	1.65	0.13	2.15
39.	1.68	0.13	2.18
40.	2.33	0.12	2.80

Table 7. Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 1, Rep C).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
1.	1.90	0.20	3.80
2.	1.81	0.20	3.62
3.	1.37	0.13	1.78
4.	1.89	0.27	5.10
5.	1.14	0.12	1.37
6.	1.45	0.11	1.60
7.	1.18	0.11	1.30
8.	0.91	0.13	1.18
9.	1.18	0.11	1.30
10.	1.16	0.12	1.39
11.	1.06	0.11	1.17
12.	1.55	0.12	1.86
13.	1.36	0.12	1.63
14.	1.63	0.14	2.28
15.	1.24	0.10	1.24
16.	1.25	0.10	1.25
17.	1.87	0.13	2.43
18.	1.88	0.19	3.57
19.	1.43	0.13	1.86
20.	0.94	0.11	1.03

Table 7. (Cont'd) Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 1, Rep C).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
21.	1.24	0.12	1.49
22.	1.11	0.11	1.22
23.	1.62	0.15	2.43
24.	1.51	0.12	1.81
25.	1.63	0.14	2.28
26.	1.68	0.19	3.19
27.	1.71	0.11	1.88
28.	1.43	0.11	1.57
29.	1.57	0.12	1.88
30.	1.43	0.11	1.57
31.	1.79	0.14	2.51
32.	1.35	0.11	1.49
33.	1.51	0.10	1.51
34.	1.18	0.10	1.18
35.	1.73	0.10	1.73
36.	1.31	0.17	2.23
37.	1.37	0.15	2.06
38.	1.43	0.11	1.57
39.	1.61	0.09	1.45
40.	1.84	0.12	2.21

Table 8. Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 2, Rep A).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
1.	2.70	0.17	4.59
2.	2.53	0.18	4.55
3.	2.42	0.15	3.63
4.	2.44	0.23	5.61
5.	1.41	0.11	1.55
6.	1.76	0.10	1.76
7.	1.58	0.10	1.58
8.	1.23	0.10	1.23
9.	1.42	0.14	2.00
10.	1.61	0.14	2.25
11.	1.16	0.17	1.97
12.	1.80	0.14	2.52
13.	1.46	0.19	2.77
14.	2.52	0.14	3.53
15.	1.58	0.10	1.58
16.	1.85	0.10	1.85
17.	2.24	0.17	3.81
18.	2.56	0.24	6.14
19.	2.44	0.11	2.68
20.	1.72	0.11	1.89

Table 8. (Cont'd) Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 2, Rep A).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
21.	2.03	0.12	2.44
22.	1.54	0.12	1.85
23.	1.83	0.18	3.29
24.	1.82	0.11	2.00
25.	2.03	0.13	2.64
26.	2.20	0.20	4.40
27.	2.36	0.12	2.83
28.	1.51	0.13	1.96
29.	2.44	0.11	2.68
30.	1.73	0.11	1.90
31.	2.38	0.18	4.28
32.	1.87	0.12	2.24
33.	2.06	0.13	2.68
34.	1.70	0.10	1.70
35.	1.96	0.14	2.74
36.	2.18	0.13	2.83
37.	2.52	0.15	3.78
38.	2.30	0.12	2.76
39.	2.35	0.11	2.59
40.	2.33	0.11	2.56

Table 9. Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 2, Rep B).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
1.	2.55	0.22	5.61
2.	2.66	0.22	5.85
3.	2.38	0.17	4.05
4.	2.48	0.25	6.20
5.	1.83	0.11	2.01
6.	1.92	0.15	2.88
7.	2.14	0.10	2.14
8.	1.26	0.15	1.89
9.	1.85	0.16	2.96
10.	1.68	0.19	3.19
11.	1.77	0.11	1.95
12.	2.23	0.17	3.79
13.	2.26	0.18	4.07
14.	2.88	0.15	4.32
15.	1.53	0.11	1.68
16.	1.76	0.12	2.11
17.	2.22	0.16	3.55
18.	2.07	0.30	6.21
19.	2.43	0.15	3.65
20.	1.78	0.12	2.14

Table 9. (Cont'd) Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 2, Rep B).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
21.	1.84	0.12	2.21
22.	1.65	0.10	1.65
23.	2.25	0.19	4.28
24.	1.73	0.11	1.90
25.	2.24	0.17	3.81
26.	2.56	0.18	4.61
27.	2.60	0.13	3.38
28.	2.06	0.12	2.47
29.	2.72	0.13	3.54
30.	1.80	0.09	1.62
31.	2.16	0.17	3.67
32.	2.03	0.11	2.23
33.	2.14	0.14	3.00
34.	1.67	0.09	1.50
35.	1.96	0.16	3.14
36.	2.63	0.14	3.68
37.	2.64	0.16	4.22
38.	2.35	0.12	2.82
39.	2.15	0.10	2.15
40.	2.70	0.12	3.24

Table 10. Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 2, Rep C).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
1.	2.59	0.16	4.14
2.	2.03	0.18	3.65
3.	2.37	0.13	3.08
4.	2.10	0.21	4.41
5.	1.17	0.11	1.29
6.	1.37	0.13	1.78
7.	1.56	0.11	1.72
8.	1.21	0.11	1.33
9.	1.38	0.15	2.07
10.	1.55	0.13	2.02
11.	1.72	0.11	1.89
12.	1.83	0.15	2.75
13.	1.44	0.15	2.16
14.	2.45	0.12	2.94
15.	1.66	0.10	1.66
16.	1.48	0.10	1.48
17.	1.90	0.16	3.04
18.	2.26	0.23	5.20
19.	2.15	0.13	2.80
20.	1.61	0.10	1.61

Table 10. (Cont'd) Tissue weights, %P, and P uptake of corn plants in growth chamber studies (Crop 2, Rep C).

Sample #	Tissue Wt. (gm)	%P (Plant)	P Uptake (mg/pot)
21.	1.57	0.12	1.88
22.	1.35	0.10	1.35
23.	1.90	0.12	2.28
24.	1.63	0.12	1.96
25.	2.22	0.13	2.89
26.	2.21	0.17	3.76
27.	1.98	0.15	2.97
28.	1.27	0.14	1.78
29.	2.35	0.10	2.35
30.	1.10	0.12	1.32
31.	2.00	0.18	3.60
32.	1.34	0.12	1.61
33.	1.83	0.10	1.83
34.	1.45	0.10	1.45
35.	1.93	0.10	1.93
36.	2.23	0.11	2.45
37.	2.35	0.13	3.06
38.	2.12	0.11	2.33
39.	1.92	0.10	1.92
40.	2.24	0.09	2.02

AN EVALUATION OF THREE CHEMICAL EXTRACTANTS FOR THE DETERMINATION OF PHOSPHORUS IN SOILS

by

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ABSTRACT

The purpose of this investigation was to ascertain the reliability of three chemical soil test methods, Bray P-1 at (1:10) and (1:50) ratios, Olsen, and Mehlich for determining the available phosphorus in Kansas soils and also to add to the general knowledge on this subject. The forty soils used in this investigation were representative of the wide range in soil conditions and fertility status found in Kansas soils.

A growth chamber study was initiated to determine the available P in the forty soils. Correlations were determined between the amount of phosphorus extracted by the various P extraction methods and the three plant factors, P uptake, %P, and dry matter yields. Of the plant factors correlated to the extracted P by the various methods, the correlations for P uptake were overall highest and had a more consistent trend from Crop 1 to Crop 2. The P uptake by corn plants would be superior for correlation to the available phosphorus in the soils.

The results of the correlation studies showed no definite superiority of any one method in predicting available phosphorus. The highest correlations were obtained on the noncalcareous soils, indicating that all three methods may be more applicable for use on noncalcareous soils as opposed to calcareous soils or a combination of the soil conditions.

The problem associated with the different methods has not been on the noncalcareous soils. The problem has been on predominately calcareous soils. More confidence may be placed in the Olsen, Mehlich, and Bray P-1(1:50) than the Bray P-1(1:10) when used on calcareous soils. Our results confirmed the reports of many other studies that the increase of the soil to solution ratio with the Bray P-1 method on calcareous soils would improve the correlations, but the differences were not found to be a significant improvement.

Due to the lack of finding a significant difference among the methods evaluated there would not be substantial reason to change from the Bray P-1(1:10) presently used in the Kansas State University Soil Testing Laboratory. However, on very calcareous soils, those interpreting soil tests must recognize the weakness of the P extraction methods.