# A COMPARISON OF FIELD METHODS OF DETERMINING THE AVAILABLE PHOSPHORUS OF SOILS

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# COMPARISON OF FIELD METHODS OF DETERMINING THE AVAILABLE PHOSPHORUS OF SOILS

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# INTRODUCTION

Considerable progress has been made in recent years in the development of methods for determining the amounts of the soluble or the so-called available[1] nutrients of plants contained in field soils. Almost all of the studies pertaining to the testing of these methods were conducted in the field in connection with long-time experimental fertilizer trials. Although the results of these researches are of practical value to agriculture, no accurate methods have yet been devised for the determination of the amounts of available plant nutrients in each separate field. Field plat experiments are still essential in order to establish the broad general principles of soil fertilization. If the experimental fields were located in a region of uniform soil type and the soil treatments applied by the farmers were uniform in character it might be possible to determine the specific fertilizer needs by field experiments. In a region where the soil types vary within short distances, however, the use of scattered experimental plats gives no reliable guide for the application of commercial fertilizers to the soil. Also, in any one region there is usually too much variation in the soil treatment given to individual farm fields to admit of an accurate determination of the fertilizer requirements by means of experimental plats.

(1) The term available phosphorus as used in this thesis means the amount of phosphorus determined by the tests used.

Farmers are interested, generally, in methods for determining the proper treatment of soils for more profitable crop production and simple, easily applied, chemical soil tests, by means of which the deficiencies of plant nutrients could be determined, would be valuable to them. In recent times soil chemists have developed a number of rapid tests for determining the amount of some of the soluble plant nutrients in soils, that may be used either in the laboratory or in the field.

A considerable amount of work has been done in the development of tests for the amount of available soil phosphorus. The determination of the amount of available soil phosphorus by means of some of the more recent methods proposed by soil chemists depends on the development of a blue color when the molybdenum of ammonium phosphomolybdate is reduced by a suitable reducing reagent.

Several of these methods have been developed quite recently and a comparison of some of them, using soil samples from the same locations on unfertilized field plats and plats fertilized with phosphatic fertilizers is the object of this thesis.

## HISTORICAL REVIEW

Some of the first researches on the determination of phosphorus in solutions, were carried out by bio-chemists who have attempted to determine the amount of phosphorus in plants, blood and urine by colorimetric methods. An original method for determining phosphorus in aqueous solutions was proposed by Deniges (4) in 1920. Deniges used a 10% ammonium molybdate solution to which was added an equal volume of strong sulphuric acid, and as a reducing agent 0.1 gram of pure tin dissolved in 2 cc. of concentrated hydrochloric acid with the aid of a 4% copper sulphate solution and then made up to a volume of 10 cc. In 1921, Florentin (6) altered the composition of the ammonium molybdate solution used by Deniges so that it was composed of 10% ammonium molybdate solution to which was added three volumes of sulphuric acid, made from equal parts of strong acid and water. This solution however must be stored in the dark in order to prevent reduction by light.

Later, Atkins (1) revived and further investigated the methods of Deniges (4) and Florentin(6) and applied his modified method to the study of soil extracts. This method consisted of making a colorimetric comparison of a standard phosphate solution with an aliquot part of the diluted soil extract, after the addition of 2 cc. of reagent A followed by 5 drops of reagent B to 100 cc. of each solution. Atkins' reagent A consisted of 100 cc. of a 10% solution of ammonium molybdate with 300 cc. of 50% sulphuric acid.

Reagent B is a stannous chloride solution prepared daily in the same manner as recommended by Deniges.

For the determination, 10 grams of air-dried soil is passed through a 100 mesh sieve and shaken for 3 or 4 hours with 50 cc. of conductivity water. 10 cc. of this liquid is centrifuged until clear, and 5 cc. of the clear extract is then diluted to 100 cc. with the conductivity water. The liquid is then treated with reagents A and B. The color of the unknown solution, which has been developed by reagent B, is compared with that of a standard solution. Atkins introduced the use of Bismarck brown in the case of slightly colored solutions and in doing so eliminated the greenish tint present in some extracts.

In 1926, Lonstein (11) proposed a method for determining the amount of available phosphorus in the soil which eliminates the disturbing effects due to the presence of silica and iron compounds in the extracts. The iron and silica are separated from the other constituents present by igniting the dry residue from the acid extract of the soil and extracting the ignited residue with sulphuric acid; the silica is filtered off and the dissolved iron is removed by the calcium acetate method.

Some of the workers in this field have attempted to use a reducing agent other than tin or stannous chloride. Bell and Doisy (2) have proposed hydroquinone as a suitable reducing agent for phosphomolybdic acid. The color produced by the reduction is intensified by making the solution alkaline and the greenish tint due to the presence of quinone is removed by the addition of sodium sulphite. The two

solutions used by Bell and Doisy (2) were (a) a 2% solution of hydroquinone in 0.1% sulphuric acid and (b) a 15% solution of sodium sulphite added to four volumes of 10% sodium carbonate solution. By this test it was possible to obtain a distinct blue color with 0.05 mg. of phosphorus in a volume of 100 cc. In using the test equal volumes of molybdate and hydroquinone solutions are added to the solution to be tested followed by five volumes of the sulphite solution. The color is then matched against the color of the standard solution.

In 1920, Fiske and Subbarrow (5) used 1:2:4 amino-naptho sulphonic acid instead of hydroquinone as a reducing agent. A comparison of the two methods seemed to show that the 1:2:4 amino-naptho sulphonic acid gave more accurate results in the presence of much more inhibiting material than was allowable when hydroquinone was used.

Parker and Fudge (13) compared the methods of Fiske and Subbarrow with Denigés coerrulo-molybdate method as modified by Atkins. They found that small amounts of phosphorus could be determined by the use of both methods, but they also found that the Deniges method was five times as sensitive as that of Fiske and Subbarrow. In a study of salt influences on these methods it was found that none of the common salts in the soil affected the color. Parker and Fudge recommended the use of the Deniges modified method because of its greater sensitivity.

In the determination of available phosphorus, in soils, there has been a great disagreement among workers in the method of extraction.

In England and the European countries 1% citric acid has been used as a standard extracting solution. In the United States a variety of solutions have been used for the extraction, some of the workers using 0.2 N. nitric acid and others using water extracts or weak sulphuric acid. The 0.2 N. nitric acid method was developed in this country mainly by Peter and Averitt(14), Stoddart (20) and Fraps (7) and this method, with the 1% citric acid method developed in England have been the most successful methods proposed.

Russell and Prescott (16) carried on some work using different acids for the extraction of soil phosphorus. They found that the strong acids such as hydrochloric, nitric, and sulphuric acid were less potent than equivalent concentrations of the weaker acids such as citric and oxalic acids. 0.1 N. hydrochloric acid and nitric acid brought out the least phosphorus, while 0.1 N. oxalic acid brought out the most phosphorus. This may be explained on the basis of adsorption, the acids that are adsorbed the most themselves dissolve more phosphorus. The authors also found that when the time of extraction was reduced to minimum the interpretation of the results would be simplified, because the composition of the liquid has suffered minimum change by interaction with the soil.

Hall and Plymen (9) studied the effects of different solvents on soil phosphorus and came to the conclusion that weak solvents give more trustworthy information as to the requirements of the soil for fertilizers than do strong solvents. According to Hall and Plymen (9) a suitable solvent should fill three requirements: (a) the quantity of phosphorus should show a wide variation in passing from a good soil

to a poor soil; (b) the quantity of phosphorus extracted should be sufficient for exact determinations; (c) the action of the solvents used should not be effected by the presence of variable constituents in the soil, such as calcium carbonate and organic matter.

Hibbard (10), in 1931, stated that citric and oxalic acids should not be used as extractants as it is necessary to remove them before the solution is tested by the molybdate method. Also, he states that the best kinds of acid to use, in the estimation of the available phosphorus in soils is one that is neither strong, highly ionized, nor slightly buffered, since such an acid will not hold the pH or the $PO_4$ concentrations constant. To be comparable all extracts should have almost the same pH and the amount of acid needed for any one soil should be determined by experiment. A 1:5 extract made by weak acid solvents was found by Hibbard to represent much better than strong acid extract the phosphorus supplying power of soils as indicated by the growth of plants on them.

Shedd (17) proposed a short, rapid test in 1920 which made use of 0.2 N. nitric acid. In his method ten grams of air-dried soil is added to 25 cc. of 0.2 N. nitric acid and the whole shaken every minute for five minutes. The solution is then filtered until clear into a test tube; 1 or 2 cc. of 60% ammonium nitrate solution is then added, and 5 cc. of ordinary molybdate solution. The contents of the tube are then heated to 60°C, shaken several times and allowed to stand about 30 minutes at room temperature. The results are then read as "large", "fair", "moderate", or "very moderate" in decreasing order of the amount of ammonium phospho-molybdate obtained. Shedd (21)

did not attempt to place the method on a quantitative basis at that time.

Truog (22) (23) has proposed a laboratory method, which has been used quite extensively in Wisconsin, for the determination of available phosphorus in soils. A 0.002 N. sulphuric acid solution, buffered to a pH of 3 is used in the extraction. Truog states that this method correlates quite well with growth of plants under Wisconsin conditions.

In Germany two workers have introduced methods for estimating the fertilizer requirement of soils by means of the growth of plants. Neubauer's method (12) is based upon the rapid absorption of soluble plant nutrients by young rye seedlings. Rye seedlings are grown in the soil for eighteen days and are then harvested and analyzed for potash and phosphorus. Neubauer determined the"limiting Value" of the soil under German conditions, as 24 mg. of $K_2O$ and 6 mg $P_2O_5$. Thornton (13) studied the Neubauer method and set the "limiting value", for Indiana farming conditions, at 4 mg. of $P_2O$ and 10 mg. of $K_2O_5$. In general Thornton found that the Neubauer method correlated with the pot and field tests that were carried out by him.

Mitscherlich's method, which is described by Stewart (19) is based on the theory that there is a quantitative relationship between the yield and the concentration of nutrients producing it. This method has met with success in Germany, but it is a slow and expensive method for determining the fertilizer requirement of the soil.

None of the methods, which have been reviewed are applicable to use in the fields. Truog has collaborated with the LaMotte Chemical Company in producing a method which can be used in the field. Spurway (18) has developed a method of determining the water soluble phosphorus of the soil. This method can be used in either the field or laboratory. Bray (3) has proposed a test for determining the relative amounts of phosphorus in the soil. All of these field methods will be discussed further under procedure and methods.

**Distribution of Fertility Plats**

**PLATE I. LOCATION OF PLATS**

## PROCEDURE AND METHODS

### Soil Samples

The soil samples used in this comparison were obtained from various station experimental plats and cooperative experimental fields in different parts of the state as shown by Plate 1. Five samples were taken from each plat at a depth of plow layer and thoroughly mixed. The soils were passed over a 10-mesh sieve and the pebbles and coarse materials taken out. All of the soils were then tested in the laboratory by the use of the various methods under the same conditions.

By following this plan it was possible to investigate a number of soil types from different sections of the state. The crop yields for the plats were obtained from the records of the fertility work of the Soils Department.

### Description of Methods

Spurway's water-soluble phosphorus method: In Spurway's (18) test for water-soluble phosphorus, the use of glassware is eliminated except for the reagent bottles. It is possible to use tap or well water, if free from phosphorus and arsenic. The determinations are made by means of a micro-chemical phosphorus test based on the reaction of Deniges. The molybdate reagent is made by dissolving five grams of C. P. ammonium molybdate in 50 cc. of distilled water. This solution of ammonium molybdate is then poured into 50 cc. of pure, concentrated nitric acid which must be phosphorus free. Then dilute this mixture with 100 cc. of distilled water. A blank test should be made on this reagent at regular intervals of time and if a blue color develops it is necessary to add 3 to 4 cc. of nitric acid to the whole quantity of reagent. Should the blue color persist it is best to discard all of

the reagent and make up a fresh supply. The tin pencil used for reducing the molybdate in the test is a rod of pure tin about three-sixteenths of an inch in diameter and three or four inches long pointed at one end.

The color chart used was developed by Spurway (18), by testing phosphorus solutions of known strengths and comparing the colors developed with the color charts of Ridgeway (15).

In performing the test a piece of waxed paper is folded lengthwise, and opened to form a trough. Some of the soil is placed in the upper end of the trough close to the hand and should fill the paper to the edges and extend about three-quarters of an inch lengthwise on the paper. A slight cavity is then made in the rear of the soil; this cavity will form a reservoir to hold the water used in the extraction. Water is then dropped behind the soil sample in the trough, slowly and carefully allowing the soil to take up the water drop by drop, the controlling the movement of water by tipping the end of the paper slightly downward. When the clear extract appears at the end of the trough a drop may be placed on a separate flat piece of waxed paper. To this drop of extract is added an equal quantity of molybdate reagent and the liquids mixed by stirring with the corner of another waxed paper. The mixture is then stirred with the tip of the tin pencil for ten seconds. If phosphorus is present in the extract, a blue color develops, and the intensity of this color is a measure of the quantity of phosphorus present in the extract. The maximum color will develop in a short time after which the color will gradually fade. According to the author the test can be used in several lines of research pertaining to soil phosphorus.

Illinois phosphate test: Bray (3) has developed a method which is commonly called the Illinois phosphate test. The solution, with which the test is carried out, is prepared by dissolving 100 grams of highest purity ammonium molybdate in 850 cc. of distilled water. This solution, after being filtered and cooled, is added with constant stirring to a cold mixture of 1700 cc. of concentrated hydrochloric acid (36%) and 700 cc. of water. This is the stock solution. The solution as used for the test is made up by diluting 120 cc. of the stock solution to 1000 cc. with distilled water. A tin rod, as recommended by Spurway (18) is used in the test.

The test is made by shaking one part of soil with three parts of the solution in a small vial or test tube. Just enough shaking to mix the soil and solution is required. After settling, which takes about five minutes, the clear solution is stirred gently with a tin rod until the maximum intensity of color is reached. The varying amounts of phosphorus are indicated by the various shades and color intensities which increase with the amount of phosphorus present. The four amounts of phosphorus are listed as "high", "medium", "doubtful" and "low" in available phosphorus. According to the author these colors fade very little on standing. The color is compared with a color chart to determine the relative amount of phosphorus in the soil.

Truog-LaMotte method: The Truog-LaMotte phosphorus test requires three reagents which are called "A", "B", and "C". The measuring spoon which is included in the outfit is filled level, with the soil. This spoonful of soil is placed in one of the extraction tubes. Distilled water is added to the mark, which is about one inch from the bottom. Then three drops of reagent "A" are added, the tube immediately stoppered and shaken for one minute. The soil suspension is then filtered into a comparison tube which has a 3 cc. mark. After 3 cc. of filtered extract is obtained, three drops of reagent "B" are added to the extract and the tube immediately shaken to mix the contents. A volume equal to a pinhead of reagent "C", which is a powder, is now added and the tube again shaken. After one minute the maximum color is developed and may be compared to the standard colors on the color chart. It is possible to read the pounds per acre of available phosphorus from this chart. It is recommended by Truog (22) that for general farming conditions in northern states, silt loam, sandy loam, and clay loam soils should contain at least 75 pounds of readily "available" phosphorus per acre and sandy soils 50 pounds per acre. Truog's laboratory method: Truog's (22) (23) laboratory method has been used with success in Wisconsin. The sulphuric acid solution, which is used for the extraction, is prepared by making a stock solution of exactly 0.1N sulphuric acid by titrating against standard alkali. The extracting solution is then prepared by diluting convenient volumes of the 0.1N sulphuric acid solution to 0.002N and buffering to a pH of 3 by adding 3 grams of ammonium sulphate per liter. The ammonium molybdate-sulphuric acid solution is prepared by dissolving 25 grams of ammonium molybdate in 200 cc. of water heated to 60°C., and filtered. 280 cc. of phosphorus- and arsenic-free sulphuric acid is diluted to 800 cc. with distilled water. After both solutions have been cooled slowly add the ammonium molybdate solution to the sulphuric acid solution. When the resulting solution has cooled to room temperature it is diluted to 1000 cc.

Stannous chloride solution is prepared by dissolving 25 grams of stannous chloride (SnCl .2H O) in 1000 cc. of dilute (10% by volume) hydrochloric acid solution. This solution is then stored in a bottle with a side opening at the bottom arranged with a glass stopcock for delivering the solution in drops. The solution is then protected from the air by floating a layer of mineral oil over the surface.

It is necessary to prepare a standard phosphate solution to use in comparison of the colors. 0.2195 grams of recrystallized potassium dihydrogen-phosphate is dissolved and diluted to 1000 cc. This solution will contain 50 ppm. of phosphorus and is too concentrated for use. A second stock solution is prepared by diluting 50 cc. of the original solution to 500 cc. This second stock solution will then contain 5 ppm. and can be used for making the standard colorimetric solution. To prepare this standard take 5 cc. of the second solution, dilute to 95 cc. with distilled water and add 4 cc. of the ammonium molybdate-sulphuric acid solution and mix. To this mixture add 6 drops of stannous chloride solution to develop the color and the solution is ready for use. It contains 0.25 ppm. of phosphorus.

In the extraction process two grams of soil and 400 cc. of 0.002 N. sulphuric acid are placed in a bottle or Erlenmeyer flask of suitable size and shaken for 30 minutes. The soil suspension is filtered off using No. 42 Whatman filter paper.(1) The filtrate is discarded until it comes through clear. For comparing the colors, intensities of the standard, and unknown solutions, a Klett colorimeter is satisfactory instead of the ordinary Nessler tubes as specified by Truog. 48 cc. of the clear filtrate are placed in an Erlenmeyer flask, then 2 cc. of the ammonium molybdate-sulphuric acid solution are added and the mixture shaken well. To this mixture three drops of the stannous chloride solution are added and the whole shaken again. The standard and the unknown solutions are then placed in the colorimetet tubes which are adjusted until the colors match. The calculations are easily made. If 50 is the reading of the unknown solution and 19.5 the reading of the standard solution the amount of available phosphorus will be $\frac{19.5 \text{ x } 50}{50 \text{ (reading of unknown}}$ or 19.5 ppm. on air dried soil. In order to convert parts per million to pounds per acre plow layer it is necessary to multiply by the factor 2 in the case of heavy soils, 2.5 for sandy soils, and somewhat less than 2 for mucks.

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(1) Truog recommended the use of S. S. 589 filter paper, but Whatman No. 42 gives good results.

## DISCUSSION OF RESULTS

There is a variation in the limiting values of plant nutrients for normal crop growth in different soil areas under different climatic conditions and these limiting values may be established only after a detailed study of all the factors involved. In this discussion, however, the limiting values recommended by the respective originators of the several phosphorus tests will be used. The values as set by the several investigators are as follows:

Truog-LaMotte method: 75 pounds per acre of available phosphorus for heavy soils and 50 pounds per acre for sandy soils.

Spurway's water-soluble phosphorus method: 0.5 ppm. of water-soluble phosphorus in the soil extract.

Illinois phosphate test: "Doubtful".

Truog laboratory method: Approximately 20-25 ppm. of available phosphorus in sandy soils and 35-40 ppm. in heavier soils.

The Mankowski fertility series, the data from which are shown in Table 1 and Figure 1 (1) is located on Roselawn sandy loam soil, which is of low fertility in the virgin state. Both Spurway's method and Truog's laboratory method showed that this soils was low in available phosphorus. The Truog-LaMotte method and the Illinois phosphate test showed no deficiency in the available phosphorus content of this soil. An application of phosphatic fertilizer to this soil produces a decrease rather than an increase in yield. In the case of plat 202, which received 200 pounds of superphosphate per acre

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(1) The graphs represent comparative values and the form of the curves is the main means of comparison.

both Spurway's method and Truog's laboratory method showed this soil to contain more available phosphorus than the soil from plat 201, yet the quantity of phosphorus was the minimum quantity required for suitable plant growth. The other methods also showed an increase in the amount of available phosphorus. However, with this addition of fertilizer plat 202 produced a smaller yield of potatoes than did the plat which received no phosphatic fertilizer. When 400 pounds of superphosphate were added to the soil as was done on plat 203 all of the methods, with the exception of the Illinois phosphate test, indicated an increase in the quantity of available phosphorus. The yield from plat 203 was greater than that from 202 but it was still lower than the yield from plat 201.

Spurway's method showed an increase in phosphorus in the sample from plat 205 over that in the sample from plat 204. Similar results were obtained by the Truog laboratory method. The quantity of phosphorus was less in plats 204 and 205 than in plat 203. The results from Spurway's and Truog's laboratory method correlated quite well with the fertilizer applications but do not correlate with the crop response to phosphatic fertilizers. The data from the Truog-LaMotte method and the Illinois phosphate test correlated the closest with the crop response to applications of phosphatic fertilizer.

The Peeble fertility series, the results from which are shown in Table 2 and Figure 1, is located on Onaway sandy loam soil. The Truog-LaMotte method, Truog's laboratory method, and Spurway 's method showed that the soil was deficient in available phosphorus, while the Illinois phosphate test indicated that the soil was well supplied with phosphorus. In this series there was a good correlation between the results from all the methods, with the exception of the Illinois phosphate test, and the crop response to phosphate applications. In the case of plats 208 and 204, to which 400 and 600 pounds of superphosphate were added, respectively, the Truog laboratory method, Spurway's method, and the Truog-LaMotte method show no increase in the amount of available phosphorus. These results correlate with the fact that there was no noticeable increase in crop yield on these plats. However, when 800 pounds of superphosphate were added to plat 205 there was an increase in the quantity of available phosphorus in the soil and a noticeable increase in the crop yield. Throughout this series there was quite a marked correlation between the results obtained by all of the methods, with the exception of the Illinois phosphate test, and the crop response to fertilizer application.

Table 3 and Figure 2 show the results from the Elsby fertility series. In this series none of the methods showed a deficiency of available phosphorus and there was very little crop response to fertilizer applications. The only plats showing a larger yield than the check plat, which received no fertilizer, are plats 5 and 7, which received 1000 pounds and 2000 pounds per acre of 4-16-8 fertilizer, respectively. This increase may have been due to the potash and nitrogen added to the soil in the fertilizer. All the methods, with the exception of the Illinois phosphate test, showed increases in the quantities of available phosphorus with increasing applications of fertilizer until 750 pounds of 4-16-8 fertilizer had been added.

The Truog-LaMotte method might have shown a further increase but this was the limit of the color chart. The Illinois phosphate test indicated that the soil was "high" in all plots. The Truog laboratory method indicated an increase in available phosphorus after 1500 pounds of 4-16-8 fertilizer had been applied.

The results of the Bird fertility series, which are shown in Table 4 and Figure 3, indicated a fair relation between the data obtained from the Truog-LaMotte method and Spurway's method, and the crop response to phosphatic fertilizers. The Illinois phosphate test and Truog's method both showed that there was a deficiency of available phosphorus in this soil. The results from the Truog-LaMotte method and Truog's laboratory method showed a good relation to the yield from plot 3, which received 500 pounds of 4-16-8 fertilizer. The yield from plot 3 was less than the yield from plot 2, which received only 250 pounds per acre of 4-16-8 fertilizer and both of the tests also showed a decrease in the quantity of available phosphorus present. There seems to be no explanation for this decrease in yield and quantity of available phosphorus, but it does show the relation between the two methods and the crop yield. Again there was a gradual increase in available phosphorus as shown by the Truog-LaMotte method and Spurway's method as the fertilizer applications were increased. The results from the Illinois phosphate test indicated that the soil was "high" in available phosphorus with the exception of plat 1, which was "medium" in available phosphorus. The results from the Truog laboratory test were inconsistent throughout as the results showed a decrease in the quantity of available phosphorus as the fertilizer application was increased.

The Demerest fertility series, the results of which are shown in Table 5 and Figure 4, was located on Roselawn sandy loam soil, a soil which is low in phosphorus. The results from all of the methods with the exception of the Illinois phosphate test showed this soil to be low in available phosphorus. A decided increase in yield was obtained when 375 pounds of 2-16-6 fertilizer were added to this soil. In the case of plat 501 Truog's laboratory method was the only method the results from which indicated a deficiency of phosphorus. When 750 pounds of 2-16-6 fertilizer were added there was an increase in yield over that of plat 501. The results from all the methods, with the exception of those from the Illinois phosphate test which were "high" throughout, showed increasing amounts of available phosphorus as the fertilizer application was increased. The best relation in this respect was between the results from the Truog laboratory method and the fertilizer applications.

Table 6 and Figure 5 showed the results from the Hopfer fertility series, which is located on Onaway sandy loam soil. With the exception of the Illinois phosphate tests, the results from all the methods showed the soil to be low in available phosphorus. However, there was no increase in crop yields to fertilizer applications. In fact, a decrease in yield occurred when fertilizer was added. All of the results from the different methods agreed with the fertilizer applications, as the quantity of available phosphorus increased with increasing fertilizer applications. When the fertilizer application was increased from 500 pounds to 1000 pounds per acre the quantity of available phosphorus was doubled as shown by the Truog-LaMotte method, Spurway's method, and Truog's laboratory method.

The results from the Orr fertility series are shown in Table 7 and Figure 5. There was sufficient phosphorus in the soil according to the results from the Illinois phosphate test and the Truog-LaMotte test. The results from Spurway's method and Truog's laboratory method showed that there was a minimum amount of phosphorus available in plats 601, 602, and 604. When 1000 pounds of 2-16-6 fertilizer were added both of the methods then showed that there was sufficient available phosphorus present for plant growth. The yield was also increased when 1000 pounds of 2-16-6 fertilizer were added so it would seem that the phosphorus-fixing power of this soil was high. If this is true Spurway's method and Truog's laboratory method must indicate the power of phosphorus fixation that is characteristic of many soils.

Table 8 and Figure 6 present the results from the Griswold fertility series, which was located on Isabella sandy loam. The results from the Illinois phosphate test indicate that there was a deficiency of available phosphorus in this soil. The results from the Truog-LaMotte and Truog's laboratory method indicated that there was a deficiency of phosphorus in the check plat, which received no superphosphate. The results from Spurway's method indicated that the available phosphorus content of the soil was low in plats 201, 202, 203, and 204. There was an increase in yield until 600 pounds of superphosphate was added. Then there was a decrease of 60 bushels per acre in the yield from that of plat 203 which received 400 pounds of superphosphate. The soil samples taken from plat 204 also showed a decrease in available phosphorus by the Truog laboratory method. When 800 pounds of superphosphate were added the yield increased 42 bushels per acre over that of plat 204. This might indicate that in some way some of the phosphorus was fixed by the soil and thus decreased the yield. It seems safe to state that there was a relation between the results from Spurway's method and the crop response to phosphatic fertilizers.

In Table 9 and Figure 7 are shown the results from the College phosphorus plats. The results from Spurway's method and Truog's laboratory method show that there was a deficiency of phosphorus in this soil and a slight increase in crop yield was obtained with phosphatic fertilizers. The results from the Truog-LaMotte method showed that the minimum amount of phosphorus necessary for crop growth was present in this soil. The Illinois phosphate test results showed that the available phosphorus was "high" in this soil. With the addition of increasing amounts of phosphorus to the soil, varying from 0 pounds of superphosphate to 250 pounds of 3-64-10 there was a change in the quantity of available phosphorus as indicated by the Truog-LaMotte method and Spurway's method. There was a slight change indicated by Truog's laboratory method of determining available phosphorus. It would appear that this soil also has a high fixing power for phosphorus applied to it. If this is true the Illinois phosphate test does not seem to be sufficiently sensitive to distinguish between phosphorus which is so fixed by the soil that it is unavailable to plants and that phosphorus which is available to the plant.

## DISCUSSION OF RESULTS FROM SOIL SAMPLES TAKEN AT VARIOUS DEPTHS

The soil samples used in this comparison were obtained from the fertility plats on the College experimental farm. The samples were obtained at the various depths by digging holes, in the various plats, to a depth of 12 inches. The samples were then taken from the walls of holes at the depths indicated in the tables. Samples were taken on two dates, May 9 and August 14 of the same summer. The crops had been harvested when the August 14 samples were taken.

The results from the 1F plat, which received no fertilizer, are shown in Table 11 and Figure 8. Truog's laboratory method showed only two samples of those taken May 9 as containing enough phosphorus for good plant growth. All of the other methods showed the samples from all of the depths to contain enough phosphorus for good plant growth.

The results from the Truog-LaMotte method showed that the August 14 samples were all low in available phosphours. All of the methods showed that the samples taken August 14 at depths of eight to ten inches and ten to twelve inches were low in available phosphorus. There was a fair agreement in the quantities of phosphorus found by the Truog-LaMotte method and Spurway's method.

The results shown in Table 12 and Figure 9 are from the 2F plat which was fertilized the previous fall with 480 pounds per acre of 20% superphosphate. The Truog laboratory method showed soil from all of the depths low in available phosphorus, with the exception of the surface layer. The Illinois phosphate test showed all samples "high" or "medium" in available phosphorus. All of the samples taken May 9, with the exception of those from the eight to ten and ten to twelve inch depths contained enough available phosphorus for plant growth according to the Truog-LaMotte test. Spurway's method showed adequate phosphorus in the soil from the one to two inch depths and the minimum quantity of phosphorus necessary for plant growth in all of the remaining samples. There is a fair relation between the results from all of the methods with the exception of the Illinois phosphate test.

The results from the 3F plat which was fertilized in the spring with 480 pounds of 20% superphosphate are shown in Table 13 and Figure 10. The results from the Illinois phosphate test indicated that there was sufficient phosphorus present for plant growth, in the soil from all depths with the exception of that from the eight to ten and ten to twelve inch depths. The surface soil according to Truog's laboratory method and the Truog-LaMotte method was well supplied with available phosphorus on May 9, while Spurway's method showed that the minimum amount of phosphorus necessary for plant growth was present. Soil from the eight to ten and ten to twelve inch depths was very deficient in phosphorus according to the results from all of the methods. All the methods showed an increase in the quantity of available phosphorus in the two lower depths from May 9 to August 14.

The 1P plat was fertilized with 250 pounds of 3-8-10 fertilizer per acre. The results from this plat are shown in Table 14 and Figure 11. The results from all of the methods, with the exception of the Illinois phosphate test, showed a deficiency of phosphorus in the soil of this plat. The Illinois phosphate tests showed that all of the samples taken May 9 were "high" in phosphorus and those taken August 14 were "medium" in phosphorus. The results from all of the other methods also indicated a decrease in the quantity of available phosphorus from May 9 to August 14.

The results of the 2P plat, which received no fertilizer, are shown in Table 15 and Figure 12. According to all of the methods, with the exception of the Illinois phosphate test, the samples taken both May 9 and August 14 were low in phosphorus as only the minimum amount of phosphorus necessary for plant growth was present. The Illinois phosphate test indicated all of the soils as "high" or "medium" in available phosphorus.

The 3P plat, the results of which are shown in Table 16 and Figure 13, was fertilized with 250 pounds of 3-16-10 fertilizer. The results from this plat are very similar to those received from the 2P plat. All of the methods agreed or correlated in that the quantity of available phosphorus in the surface layer decreased from the time of the first sampling to the time of the second sampling.

The results from the 4P plat, which was fertilized with 250 pounds of 3-32-10 per acre, are shown in Table 17 and Figure 14. The results from all of the methods agreed fairly well although the Illinois phosphate test showed all of the samples to contain somewhat more phosphorus than did the other methods.

Table 18 and Figure 15 present the results from the 5P plat which was fertilized with 250 pounds of a 3-64-10 fertilizer. Again all of the data agreed in showing that all of the samples were relatively high in available phosphorus.

Throughout this series all of the methods, excepting the

Illinois phosphate test, agreed with each other in the quantities of available phosphorus found. When a plat had been heavily fertilized with a phosphatic fertilizer the results from all of the methods indicated an increase in available phosphorus. However, the Illinois phosphate test does not indicate a larger quantity and so the results from it could not correlate closely with those from the other methods.

## THE USE OF BUFFERED AND UNBUFFERED EXTRACTING SOLUTIONS IN THE TRUOG LABORATORY METHOD

Truog's laboratory method (14) calls for the use of a 0.002 N. sulphuric acid solution, buffered to a pH of 3 with ammonium sulphate for the extraction of available phosphorus from soils. The writer attempted to determine if there was any difference in results when an unbuffered solution was used instead of the buffered solution. No changes were made in the method except that unbuffered 0.002 N. sulphuric acid solution was used instead of a buffered 0.002 N. sulphuric acid solution.

In Table 15 and Figures 8, 9, and 10 are shown the results obtained from this work. Very little difference was found in the amounts of phosphorus extracted by the two different solutions but in the majority of cases the unbuffered solutions extracted more phosphorus than the buffered solutions.

## GENERAL DISCUSSION OF RESULTS

In this discussion the results will be taken up according to the location of the plats in the different sections of the State and with regard to the various soil types. The lower peninsula of the State can be divided into the northern lower peninsula and southern lower peninsula. Otsego and Antrim counties are included in the northern lower peninsula group, while Kent, Montcalm, Ionia, Ingham, and Kalamazoo counties are included in the southern lower peninsula. The Mankowski, Demerest, Peeble, and Hopfer fertility series are in the northern half of the lower peninsula. The Mankowski series showed a relation between the Truog-LaMotte method and Spurway's water-soluble phosphorus method. The crop yields were quite variable and the Truog-LaMotte method did not correlate well with them. The Demerest fertility series shows a very good response to fertilizer. The relation between the Illinois phosphate test and the response to fertilizer is very poor as the Illinois phosphate test shows a high phosphorus content throughout the series. When the Truog-LaMotte method and Spurway's method show a soil deficient in available phosphates, in the majority of cases that soil will respond to phosphatic fertilizers. The relation between the Truog laboratory method and the response to fertilizer is good. In the Peeble fertility series a fair relation is shown between the Spurway, Truog-LaMotte method, and Truog's laboratory method and the crop response to fertilizer. There is a poor relation between the results of the Illinois phosphate test and the crop response to fertilizers. The same results were found with the Hopfer fertility series.

In the southern part of the lower peninsula are the Orr, Elsby, Griswold, Bird, College plats, and the Kalamazoo fertility series.

In this section of the State the Illinois phosphate test again shows few correlations. This test often shows the soil as "high" in available phosphorus and yet there is a variable crop response to the fertilizers. Also, the test seems to lack sensitivity as it fails to show the great differences in the amount of available phosphorus, present in the soil due to fertilizer applications. The Truog laboratory method works well in the southern part of the lower peninsula. The results from the method correlate with the crop response of the plots to fertilizer treatments and this method also shows differences in the amounts of available phosphorus in the soils studied. The Truog-LaMotte method and Spurway's water-soluble method both generally show a correlation with the crop yields and fertilizer applications of the various fertility plats. These methods show differences in the amounts of available phosphorus for the plats. If the crop yields are increased by phosphate fertilizers both of these methods generally show the untreated plat as being low in available phosphorus. From these comparisons there is very little difference between the results obtained by these two methods on soils in the various parts of the lower peninsula.

In Table 19 is shown a comparison between the Truog-LaMotte method of determining available phosphorus and Truog's laboratory method of determining available phosphorus. The largest number of soils are shown as containing 20-30 ppm. of available phosphorus by the Truog laboratory method and the same soils contain 75 pounds of available phosphorus per acre by the Truog-LaMotte method. As the amount of available phosphorus in the soil increases by the Truog laboratory method the amount of phosphorus increases by the Truog-LaMotte method.

In Table 20 is shown a comparison between the Illinois phosphate test and the Truog laboratory method. The Truog laboratory method shows 45 soils as containing 30-40 ppm. of available phosphosus while the Illinois phosphate test shows the same soils as "high". Truog's laboratory method shows 40 soils as containing 10-20 ppm. of available phosphorus, while the Illinois phosphate tests shows these same soils as "medium". 10-20 ppm. of available phosphorus would indicate that the soil is low in available phosphorus.

In Table 21 is shown a comparison between Spurway's water-soluble phosphorus method and Truog's laboratory method. The largest number of soils are shown as containing 10-20 ppm. of available phosphorus in the soil by Truog's laboratory method while Spurway's method shows that the water extracts of those same soils contain 0.5 ppm. of phosphorus. Also 40 of the soils contain 20-30 ppm. of available phosphorus by the Truog laboratory method while they are shown as containing 0.5 ppm. of phosphorus in the water extract by Spurway's method. As the amount of water-soluble phosphorus increases by Spurway's method the amount of available phosphorus increases by Truog's laboratory method.

The results from the Illinois phosphate test did not correlate with the yield data from the plats receiving fertilizer treatments. Usually, if the soil was deficient in phosphorus the

Illinois phosphate test showed it as "high" or "medium" in available phosphorus. Fraps (8) found that the Illinois phosphate test was quite variable with different analysts and with the same analyst at different times. Fraps also found that soils containing 30 ppm. of active phosphoric acid were classed as high by this method. The active phosphoric acid in this case is the amount removed from the soil by 0.2 N nitric acid.

The Truog-LaMotte method showed a fair correlation with the crop results from the different soil plats. It showed similar results in both the northern and southern part of the lower peninsula.

Similar results were obtained with Spurway's water-soluble phosphorus method. This method correlated quite well with the Truog-LaMotte method in most of the cases studied. When one of these methods showed a deficiency of phosphorus the other method would show similar results. Spurway's water-soluble phosphorus method also showed similar correlations when used in connection with soils from the northern or southern part of the State.

The Truog laboratory method in most cases correlated quite well with the results obtained from the different fertility series throughout the State. It can be said that the Truog laboratory method showed the variations in phosphorus content between the different plats more closely than the other methods, but this difference can be accounted for by the wider range of results obtainable with this method. In the determination of the plant nutrient deficiencies of soils by chemical tests it is perhaps not necessary to distinguish between small differences. The results may vary considerably and still indicate roughly the condition of the soil with respect to the supply of plant nutrients. This method, however, did correlate quite well with the Truog-LaMotte method and Spurway's water-soluble phosphorus method.

## CONCLUSIONS

A comparison of four methods, for the determination of the available phosphorus of soils, was made on soil samples taken from different station fertility plots. Three of the methods, Spurway's water-soluble phosphorus method, the Illinois phosphate test, and the Truog-LaMotte method are fundamentally field tests, while the fourth is Truog's laboratory method.

The results from the Illinois phosphate test showed a poor correlation with the crop response of the soils to phosphatic fertilizer treatments. The test showed very little difference between soils deficient in phosphorus and those containing a large amount of phosphorus as judged from fertilizer applications and crop yields. The Illinois phosphate test as used in this research has shown a tendency to show phosphorus deficient plats as high in phosphorus. The limiting value of phosphorus in this test in most cases could be established as "medium" for this test. Very few soils were found by this method which showed "low" or doubtful".

The results from the Truog-LaMotte method showed a fair correlation with the crop response of the soil to phosphatic fertilizers.

The results from Truog's laboratory method showed a fair correlation with the crop response of the soil to phosphatic fertilizer. However, when large amounts of phosphorus were present in the soil as indicated by the Truog-LaMotte method and fertilizer applications, Truog's laboratory method did not indicate this large amount. Only one standard is used in this method and that may account for this variation due to the wide difference between the depth of color developed by the standard and the unknown. Because of this wide variation it is not possible to read as accurately when large amounts of phosphorus are present.

The results obtained by Spurway's water-soluble phosphorus method correlate fairly well with the results obtained by the use of phosphatic fertilizers.

The limiting values as established by Truog-LaMotte method, Spurway's water-soluble phosphorus method, and Truog's laboratory method correlate quite well with all of the results obtained in this study. The Truog-LaMotte method and Spurway's water-soluble phosphorus method could both be recommended as field methods of determining phosphorus deficient soils under Michigan conditions. Truog's laboratory method could be recommended for use in the laboratory to determine the available phosphorus of soils although it is not as rapid as the Truog-LaMotte method and Spurway's water-soluble phosphorus method.

The main difference between all of these methods is in the method of extraction of the phosphorus from the soil, and it is thought a better means of extraction should be developed—a method which would show more clearly the true status of the available phosphorus in the soil under different moisture contents and fertilizer treatments.

## Literature Cited

(1) Atkins, W. R. J. The rapid determination of available phosphate in soil by the caerulo-molybdate reaction of Deniges. Journal of Agricultural Science, 4:192-197, 1924.

(2) Bell, R. D. and Daisy, A. L. Rapid colorimetric methods for the determination of phosphorus in urine and blood. Journal of Biological Chemistry, 44:55-67, 1920.

(3) Bray, R. H. A field test for available phosphorus in soils. Illinois Agricultural Experiment Station Bulletin 337, 1929.

(4) Deniges, D. An extremely sensitive reaction of phosphate and arsenates and its application. Compt. Rind., 171:802-804, 1920. (Abstracted in Chemical Abstract, 15: 218, 1921.)

(5) Fiske, C. H. and Subbarrow, Y. The colorimetric determination of phosphorus. Journal of Biological Chemistry, 66: 375-400, 1925.

(6) Florentin, D. The determination of phosphate in waters. Ann. Chem. Anal. Chem. Appl., 3:295-296. (Abstracted in Chemical Abstract, 16: 201, 1922.)

(7) Fraps, G. S. Active phosphoric acid and its relation to the needs of the soil for phosphoric acid in pot experiments. Texas Agricultural Experiment Station Bulletin 126: 1.

(8) Fraps, G. S. How reliable are existing chemical methods for determining soil deficiencies in ash constituents of plants. Journal of Americal Society of Agronomy, 23: 337-352, 1931.

(9) Hall, A. D. and Plymen, F. J. Determination of available plant food in soils by use of weak acid soluents. Transactions of Chemical Society, 81: 117-144, 1906.

(10) Hibbard, P. L. Chemical methods for estimating the availability of soil phosphate. Soil Science, 31: 437-467, 1931.

(11) Lonstein, I. Rapid colorimetric determinations of phosphates in soils and vegetation. Journal South Africa Institute, 10: 49-50, 1927.

(12) Neubauer, H. Determination of the potash phosphate requirements of soils by the seedling method. Trans. 2nd Comm. Interm. Soc. Soil Sci., a: 159-170. 1929. (Chem. Abst. 24: 4573, 1930)

(13) Parker, F. W. and Fudge, J. F. Soil phosphorus studies: I The colorimetric determination of organic and inorganic phosphorus in soil extracts and the soil solution. Soil Science, 24: 109-118, 1927.

(14) Peter, A. M. and Averitt, S. D. Soils. Kentucky Agricultural Experiment Station Bulletin 126, 1906.

(15) Ridgeway, R. A. Color standards and nomenclature. Hoen and Company, Baltimore, Maryland.

(16) Russell, E. J. and Prescott, J. A. The reaction between dilute acids and the phosphorus compounds of the soil. Journal of Agricultural Science, 8: 65-110, 1916.

(17) Shedd, O. M. A short test for easily soluble phosphates in soils. Soil Science 11: 111-122, 1921.

(18) Spurway, C. H. A test for water-soluble phosphorus. Michigan Agricultural Experiment Station Technical Bulletin 101. 1929.

(19) Stewart, R. The manurial requirements of soils. (Two modern methods of estimation). The Scottish Journal of Agriculture, 12: No. 3, 1929.

(20) Stoddart, C. W. Soil acidity in its relation to lack of available phosphates. Journal Industrial and Engineering Chemistry, 1: 69-74, 1909.

(21) Thornton, S. F. Experiences with the Neubauer method for determining mineral nutrient deficiencies in soils. Journal of American Society of Agronomy, 33: 195-208, 1931.

(22) Truog, Emil and Meyer, A. H. Improvements in the Deniges colorimetric method for phosphorus and arsenic. Industrial and Engineering Chemistry, 1: 136-139, 1929.

(23) Truog, Emil. The determination of the readily available phosphorus of soils. Journal of American Society of Agronomy, 22: 874-882, 1930.

TABLE I. Mankowski Fertility Series (Roselawn sandy loam)

| Plat | Treatment* | Truog-LaMotte Lbs. available phosphorus per Acre. | Spurway Water soluble phosphorus P. P. M. | Illinois phosphate test | Truog laboratory P. P. M. | Yield Bushels Potatoes |
|---|---|---|---|---|---|---|
| 201 | 0-A.P.** | 75 | 0 | M | 19.6 | 221.8 |
| 202 | 200-A.P. | 100 | 0.5 | H | 26.2 | 201.9 |
| 203 | 400-A.P. | 150 | 1.0 | H | 50.0 | 218.1 |
| 204 | 600-A.P. | 150 | 1.0 | H | 32.1 | 234.7 |
| 205 | 800-A.P. | 150 | 2.0 | H | 45.5 | 223.4 |

TABLE II. Peeble Fertility Series (Onaway sandy loam)

| Plat | Treatment* | Truog-LaMotte Lbs. available phosphorus per Acre. | Spurway Water soluble phosphorus P. P. M. | Illinois phosphate test | Truog laboratory P. P. M. | Yield Bushels Potatoes |
|---|---|---|---|---|---|---|
| 201 | 0-A.P. | 50 | 0.5 | H | 24.4 | 179.8 |
| 202 | 200-A.P. | 50 | 1.0 | H | 25.8 | 210.1 |
| 208 | 400-A.P. | 75 | 1.0 | H | 36.3 | 224.9 |
| 204 | 600-A. P. | 75 | 1.0 | H | 34.5 | 225.3 |
| 205 | 800-A.P. | 150 | 2.0 | H | 68.5 | 250.9 |

* 100 lbs. $NaNO_3$ and 100 lbs. KCl on each plat
**A. P. is Acid Phosphate

TABLE III. **Elsby Fertility Series**

| Plat | Treatment | Truog-LaMotte Lbs. available phosphorus per acre. | Spurway Water soluble phosphorus P. P. M. | Illinois phosphate test | Truog laboratory P. P. M. | Yield Bushels Potatoes |
|---|---|---|---|---|---|---|
| 1 | Check | 100 | ½ | H | 40.1 | 122 |
| 2 | 250 lbs. 4-16-8 | 100 | ½ | H | 35.1 | 123.8 |
| 3 | 500 lbs. 4-16-8 | 150 | 1 | H | 44.4 | 118.4 |
| 4 | 750 lbs. 4-16-8 | 200 | 2 | H | 23.5 | 125.3 |
| 5 | 1000 lbs. 4-16-8 | 200 | 2 | H | 36.0 | 137.6 |
| 6 | 1500 lbs. 4-16-8 | 200 | 2 | H | 54.0 | 126.7 |
| 7 | 2000 lbs. 4-16-8 | 200 | 2 | H | 72.2 | 140.1 |

TABLE IV **Bird Fertility Series**

| Plat | Treatment | Truog-LaMotte Lbs. available phosphorus per acre. | Spurway Water soluble phosphorus P. P. M. | Illinois phosphate test | Truog laboratory P. P. M. | Yield Bushels Potatoes |
|---|---|---|---|---|---|---|
| 1 | Check | 75 | ½ | M | 51.7 | 171.7 |
| 2 | 250 lbs. 4-16-8 | 100 | 1 | H | 48.0 | 192.9 |
| 3 | 500 lbs. 4-16-8 | 75 | 1 | H | 36.9 | 179.8 |
| 4 | 750 lbs. 4-16-8 | 150 | 1 | H | 35.0 | 207.0 |
| 5 | 1000 lbs. 4-16-8 | 150 | 1 | H | 52.6 | ------ |
| 6 | 1500 lbs. 4-16-8 | 200 | 2 | H | 63.2 | 211.9 |
| 7 | 2000 lbs. 4-16-8 | 200 | 2 | H | 51.1 | 215.4 |

TABLE V. Demerest Fertility Series (Roselawn sandy loam)

| Plat | Treatment | Truog-LaMotte Lbs. available phosphorus per acre. | Spurway Water soluble phosphorus P. P. M. | Illinois phosphate test | Truog laboratory P. P. M. | Yield Bushels Potatoes |
|---|---|---|---|---|---|---|
| 500 | Check | 75 | ½ | H | 27.2 | 37.0 |
| 501 | 375 lbs. 2-16-6 | 100 | 1 | H | 30.3 | 84.1 |
| 502 | 750 lbs. 2-16-6 | 200 | 1 | H | 59.5 | 109.8 |
| 503 | 1500 lbs. 2-16-6 | 200 | 2 | H | 69.7 | 112.2 |

TABLE VI. Hopfer Fertility Series (Onaway sandy loam)

| Plat | Treatment | Truog-LaMotte Lbs. available phosphorus per acre. | Spurway Water soluble phosphorus P. P. M. | Illinois phosphate test | Truog laboratory P. P. M. | Yield Bushels Potatoes |
|---|---|---|---|---|---|---|
| 602 | Check | 25 | 0 | M | 13.7 | 220.4 |
| 601 | 250 lbs. 2-16-6 | 25 | ½ | M | 19.4 | 205.4 |
| 603 | 500 lbs. 2-16-6 | 75 | ½ | H | 30.3 | 221.2 |
| 605 | 1000 lbs. 2-16-6 | 150 | 1 | H | 66.5 | 211.0 |

TABLE VII. Orr Fertility Series (Isabella sandy loam)

| Plat | Treatment* | Truog-LaMotte Lbs. available phosphorus per acre. | Spurway Water soluble phosphorus P. P. M. | Illinois phosphate test | Truog laboratory P. P. M. | Yield Bushels Potatoes |
|---|---|---|---|---|---|---|
| 601 | Check | 75 | 0 | H | 38.8 | 149 |
| 602 | 250 lbs.<br>2-16-6 | 100 | ½ | H | 34.7 | 142 |
| 604 | 500 lbs.<br>2-16-6 | 100 | ½ | H | 39.7 | 148.3 |
| 605 | 1000 lbs.<br>2-16-6 | 150 | 1 | H | 47.8 | 166.5 |

TABLE VIII. Griswold Fertility Series (Isabella sandy loam)

| | | | | | | |
|---|---|---|---|---|---|---|
| 201 | 0-A. P. | 75 | 0 | H | 29.2 | 186.5 |
| 202 | 200-A. P. | 150 | ½ | H | 41.3 | 260.1 |
| 203 | 400-A. P. | 150 | ½ | H | 58.5 | 282.7 |
| 204 | 600-A. P. | 150 | ½ | H | 52.3 | 222.8 |
| 205 | 800-A. P. | 200 | 1 | H | 68.9 | 264.9 |

* 67 lbs. $NaNO_3$ and 133 lbs. KCl on each plat in Table VIII.

TABLE IX

## College Phosphorus Plots

| Plat | Treatment | Truog-LaMotte Lbs. available phosphorus per acre. | Spurway Water Soluble phosphorus P. P. M. | Illinois phosphate test | Truog Laboratory P. P. M. | Yield Bushels Oats |
|---|---|---|---|---|---|---|
| 1 | 250 lbs. 3-8-10 | 50 | 0 | H | 31.5 | 45.0 |
| 2 | 0-0-0 | 75 | 0 | H | 34.8 | 31.5 |
| 3 | 250 lbs. 3-16-10 | 75 | 0 | H | 31.5 | 35.4 |
| 4 | 250 lbs. 3-32-10 | 75 | 0 | H | 37.5 | 40.6 |
| 5 | 250 lbs. 3-64-10 | 75 | 0 | H | 50.5 | 39.6 |
| 6 | 0-A. P. | 75 | 0 | H | 26.2 | 44.0 |

TABLE X

## Fall Fertilization Series

|  |  |  |  |  |  | Rye |
|---|---|---|---|---|---|---|
| 1 | Check | 25 | 0 | M | 16.8 | 43.7 |
| 2 | Fall F. 480#20% | 100 | 0.5 | H | 36.6 | 41.2 |
| 3 | Spring F. 480#20% | 100 | 0 | H | m 35.0 | 37.6 |

TABLE XI Samples taken from College Fall Fertilization Series. The samples were taken at different depths as indicated.

| Plat and Treatment | Truog-LaMotte | | Spurway water soluble phosphorus | | Illinois phosphate test | | Truog laboratory P. P. M. | |
|---|---|---|---|---|---|---|---|---|
| Plat 1F No phosphate | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 |
| Surface A | 75 | 25 | 0.5 | 0 | M | M | 18.7 | 16.3 |
| Surface B | 75 | 25 | 0.5 | 0 | M | M | 20.6 | 15.5 |
| 0-1 inches | 75 | 50 | 0.5 | 0.5 | M | M | 21.1 | 19.7 |
| 1-2 inches | 50 | 50 | 0.5 | 0.5 | M | M | 20.7 | 13.8 |
| 2-3 inches | 50 | 50 | 0.5 | 0.5 | M | M | 18.9 | 17.2 |
| 3-4 inches | 75 | 50 | 0.5 | 0.5 | M | M | 17.2 | 17.9 |
| 4-6 inches | 75 | 25 | 0.5 | 0.5 | M | M | 14.5 | 17.7 |
| 6-8 inches | 75 | 25 | 0.5 | 0 | H | M | 23.6 | 16.2 |
| 8-10 inches | 75 | 10 | 0.5 | 0 | H | D | 40.2 | 10.2 |
| 10-12-inches | 75 | 10 | 1.0 | 0 | H | D | 37.2 | 8.8 |

TABLE XII Samples taken from College Fall Fertilization Series. The samples were taken at different depths as indicated

| Plat and Treatment | Truog-LaMotte | | Spurway water soluble phosphorus | | Illinois phosphate test | | Truog laboratory P. P. M. | |
|---|---|---|---|---|---|---|---|---|
| Plat 2F.Fall 480 lbs. 20% superphosphate | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 |
| Surface | 100 | 100 | 1 | ½ | H | H | 48.4 | 36.6 |
| 0-1 inches | 100 | 100 | 1 | ½ | H | H | 36.1 | 30.2 |
| 1-2 inches | 100 | 100 | 1 | ½ | H | H | 34.2 | 23.8 |
| 2-3 inches | 75 | 75 | ½ | ½ | H | H | 35.0 | 21.1 |
| 3-4 inches | 100 | 75 | ½ | ½ | H | H | 26.6 | 24.0 |
| 4-6 inches | 50 | 100 | ½ | ½ | M | H | 13.3 | 38.1 |
| 6-8 inches | 50 | 75 | ½ | ½ | M | H | 12.9 | 33.2 |
| 8-10 inches | 10 | 100 | ½ | 0 | M | H | 17.9 | 38.7 |
| 10-12 inches | 10 | 75 | ½ | 0 | M | H | 22.9 | 22.7 |

TABLE XIII Samples from the College Fall Fertilization plats. Samples taken at different depths

| Plat and Treatment | Truog-LaMotte | | Spurway water soluble phosphorus | | Illinois phosphate test | | Truog laboratory P. P. M. | |
|---|---|---|---|---|---|---|---|---|
| Plat 3F.Spring 480 lbs. 20% superphosphate | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 |
| Surface | 150 | 100 | 0.5 | 0 | H | H | 45 | 34.7 |
| 0-1 inches | 100 | 100 | 0.5 | 0.5 | H | H | 37.4 | 35 |
| 1-2 inches | 75 | 75 | 0.5 | 0 | H | H | 24.2 | 37.2 |
| 2-3 inches | 75 | 75 | 0.5 | 0 | H | H | 22.4 | 25.7 |
| 3-4 inches | 75 | 75 | 0.5 | 0 | H | H | 26.8 | 24.5 |
| 4-6 inches | 75 | 75 | 0.5 | 0.5 | H | H | 41.9 | 29.5 |
| 6-8 inches | 50 | 75 | 0.5 | 0.5 | M | H | 9.6 | 34.5 |
| 8-10 inches | 10 | 75 | 0 | 0.5 | L | M | Very low | 18.2 |
| 10-12 inches | 10 | 50 | 0 | 0.5 | L | M | low | 14.6 |

TABLE XIV Samples from the College Phosphorus plats. Samples taken at different depths

| Plat and Treatment | Truog-LaMotte | | Spurway water soluble phosphorus | | Illinois phosphate test | | Truog laboratory P. P. M - | |
|---|---|---|---|---|---|---|---|---|
| Plat 1P<br>250 lbs.<br>3 - 8 - 10 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 |
| Surface | 75 | 50 | ½ | ½ | H | M | 18.5 | 23.0 |
| 0-1 inches | 75 | 50 | ½ | ½ | H | M | 32.3 | 23.5 |
| 1-2 inches | 75 | 50 | ½ | ½ | H | M | 32.4 | 14.2 |
| 2-3 inches | 75 | 50 | ½ | ½ | M | M | 30.8 | 16.7 |
| 3-4 inches | 75 | 50 | ½ | 1 | M | M | 30.6 | 18.6 |
| 4-6 inches | 75 | 50 | ½ | ½ | M | M | 23.5 | 16.2 |
| 6-8 inches | 100 | 50 | 1 | ½ | H | M | 31.6 | 15.7 |
| 8-10 inches | 75 | 50 | 1 | ½ | H | M | 30.5 | 10.5 |
| 10-12 inches | 75 | 50 | 1 | 0 | H | M | 17.0 | 19.4 |

TABLE XV Samples taken from College Phosphorus plats. Samples taken at different depths

| Plat and Treatment | Truog-LaMotte | | Spurway water soluble phosphorus | | Illinois phosphate test | | Truog laboratory P. P. M. | |
|---|---|---|---|---|---|---|---|---|
| Plat 2P No fertilizer | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 |
| Surface | — | 50 | — | 0.5 | — | M | — | 19.6 |
| 0-1 inches | 75 | 75 | 0.5 | 0.5 | H | M | 17.2 | 24.9 |
| 1-2 inches | 75 | 75 | 0.5 | 0.5 | H | M | 18.7 | 22.9 |
| 2-3 inches | 75 | 75 | 0 | 0.5 | H | M | 19.9 | 22.1 |
| 3-4 inches | 75 | 75 | 0.5 | 0.5 | H | M | 17.9 | 21.5 |
| 4-6 inches | 75 | 75 | 0.5 | 0.5 | H | H | 21.8 | 18.1 |
| 6-8 inches | 100 | 75 | 0.5 | 0.5 | H | H | 35.3 | 19.8 |
| 8-10 inches | 75 | 50 | 0.5 | 0.5 | H | H | 24.2 | 15.1 |
| 10-12 inches | 75 | 25 | 0.5 | 0.5 | H | H | 19.7 | 14.4 |

TABLE XVI Samples taken from College Phosphorus plats. Samples taken at different depths.

| Plat and Treatment | Truog-LaMotte | | Spurway water soluble phosphorus | | Illinois phosphate test | | Truog laboratory P. P. M. | |
|---|---|---|---|---|---|---|---|---|
| Plat 3P 250 lbs. 3-16-10 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 |
| Surface | 100 | 75 | 1.0 | 0.5 | H | M | 32.9 | 19.0 |
| 0-1 inches | 75 | 75 | 0.5 | 0.5 | H | M | 28.2 | 19.3 |
| 1-2 inches | 75 | 75 | 0.5 | 0.5 | H | M | 23.6 | 14.8 |
| 2-3 inches | 75 | 75 | 0.5 | 0.5 | H | M | 19.4 | 15.6 |
| 3-4 inches | 75 | 75 | 0.5 | 0.5 | H | M | 18.3 | 17.3 |
| 4-6 inches | 75 | 75 | 0.5 | 0.5 | H | M | 19.3 | 15.3 |
| 6-8 inches | 75 | 50 | 0.5 | 0. | H | M | 20.3 | 21.4 |
| 8-10 inches | 75 | 75 | 0.5 | 0.5 | H | M | 19.1 | 21.0 |
| 10-12 inches | 75 | 50 | 0.5 | 0. | H | M | 17.6 | 12.3 |

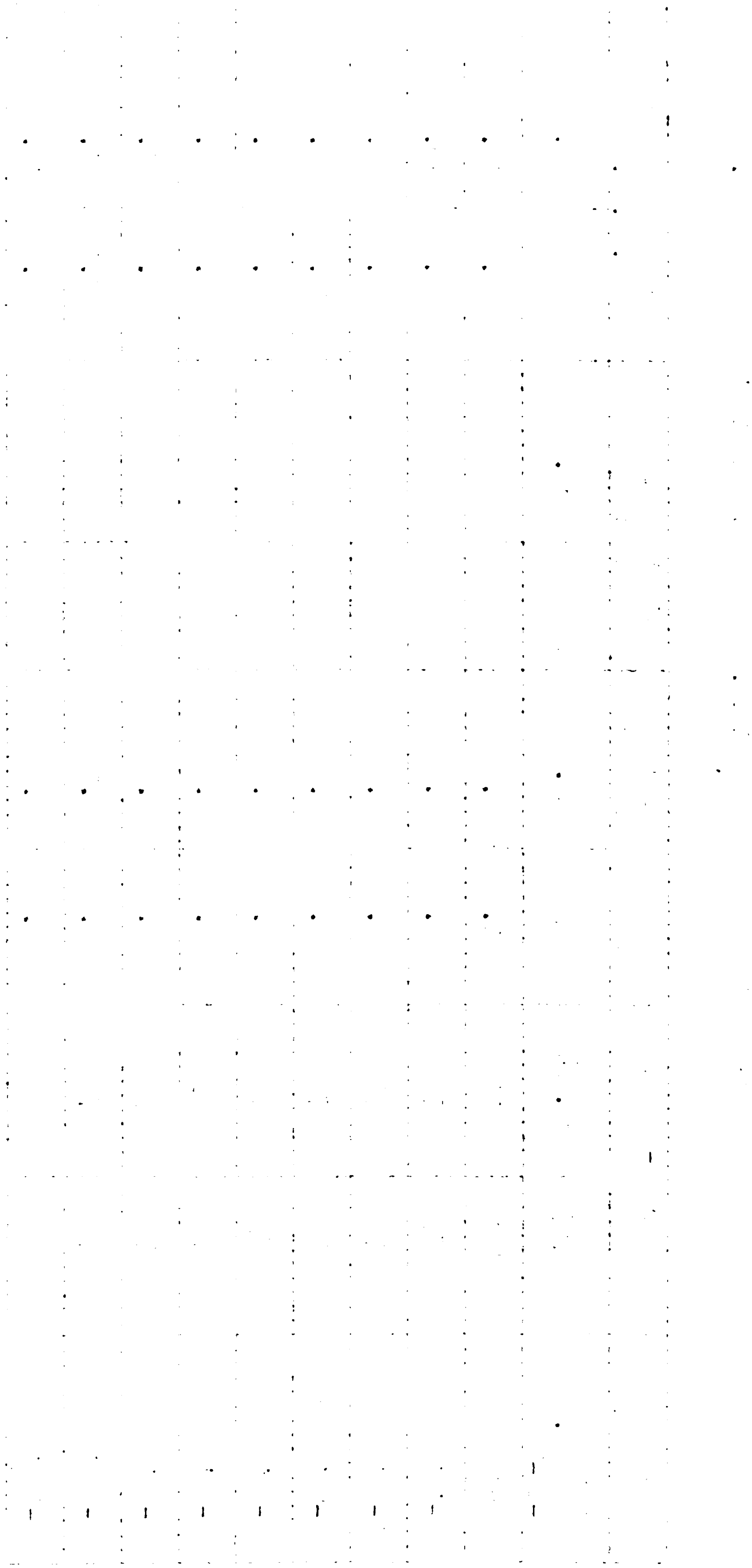


TABLE XVII Samples taken from College Phosphorus plats. Samples taken at different depths

| Plat and Treatment | Truog-LaMotte | | Spurway water soluble phosphorus | | Illinois phosphate test | | Truog laboratory P. P. M. | |
|---|---|---|---|---|---|---|---|---|
| Plat 4P<br>250 lbs.<br>3-32-10 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 |
| Surface | 100 | 100 | 0.5 | 1.0 | H | H | 39.4 | 30.2 |
| 0-1 inches | 100 | 100 | 1.0 | 1.0 | H | H | 54.8 | 24.3 |
| 1-2 inches | 100 | 100 | 1.0 | 1.0 | H | H | 34.8 | 22.7 |
| 2-3 inches | 100 | 100 | 1.0 | 0.5 | H | H | 24.3 | 25.8 |
| 3-4 inches | 75 | 100 | 1.0 | 0.5 | H | H | 24.3 | 26.5 |
| 4-6 inches | 75 | 100 | 0.5 | 0.5 | H | H | 20.5 | 19.8 |
| 6-8 inches | 75 | 75 | 0.5 | 0.5 | H | H | 17.0 | 12.9 |
| 8-10 inches | 25 | 50 | 0.5 | 0.5 | H | M | 10.8 | 9.3 |
| 10-12 inches | 10 | 10 | 0.5 | 0.0 | D | D | 8.3 | M. blue coler |

TABLE XVIII Samples taken from College Phosphorus plats. Samples taken at different depths

| Plat and Treatment | Truog-LaMotte | | Spurway water soluble phosphorus | | Illinois phosphate test | | Truog laboratory P. P. M. | |
|---|---|---|---|---|---|---|---|---|
| Plat 5P<br>250 lbs.<br>3-64-10 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 | May 9 | Aug. 14 |
| Surface | 150 | 150 | 1.0 | 1.0 | H | H | 47.8 | 68.9 |
| 0-1 inches | 150 | 150 | 1.0 | 1.0 | H | H | 54.9 | 85.1 |
| 1-2 inches | 150 | 150 | 1.0 | 1.0 | H | H | 38.4 | 72.4 |
| 2-3 inches | 100 | 150 | 1.0 | 1.0 | H | H | 35.3 | 53.8 |
| 3-4 inches | 75 | 150 | 1.0 | 1.0 | H | H | 30.2 | 48.7 |
| 4-6 inches | 75 | 150 | 1.0 | 1.0 | H | H | 33.3 | 48.8 |
| 6-8 inches | 75 | 150 | 0.5 | 0.5 | H | H | 31.5 | 48.7 |
| 8-10 inches | 100 | 100 | 1.0 | 0.5 | H | H | 40.7 | 18.0 |
| 10-12 inches | 75 | 50 | 0.5 | 0.5 | H | M | 30.7 | 12.9 |

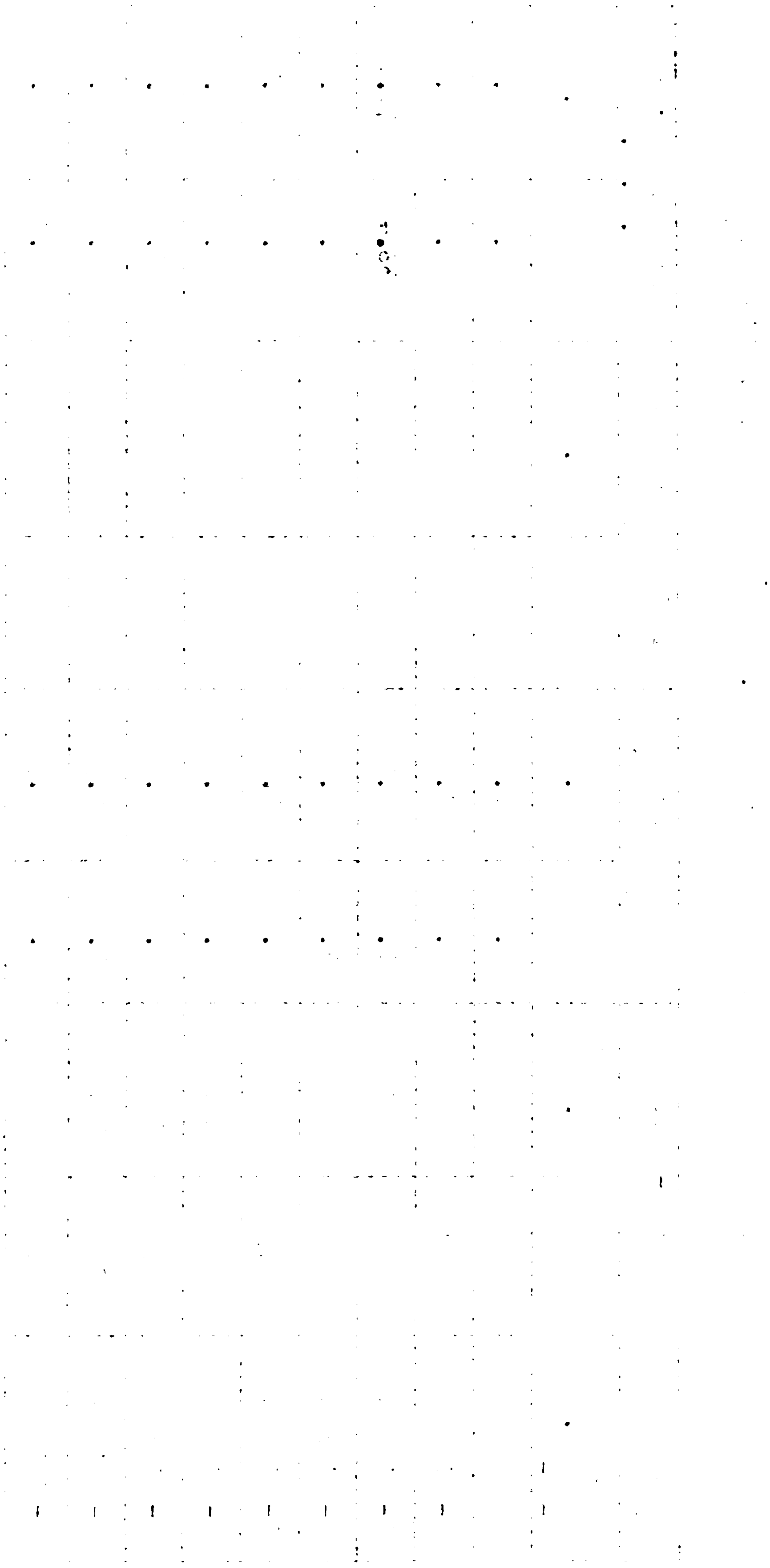


TABLE XIX A Comparison of Truog laboratory method and the Truog-LaMotte Field Method

| Truog-LaMotte Pounds/Acre | Truog Laboratory Method--P. P. M. Available Phosphorus | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | Over 80 |
| 10 | 7 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 1 | 13 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 2 | 24 | 8 | 1 | 1 | 0 | 0 | 0 | 0 |
| 75 | 0 | 29 | 32 | 24 | 3 | 2 | 0 | 1 | 0 |
| 100 | 0 | 1 | 11 | 19 | 8 | 1 | 0 | 1 | 0 |
| 150 | 0 | 0 | 0 | 3 | 11 | 7 | 4 | 1 | 2 |
| 200 | 0 | 0 | 1 | 1 | 0 | 3 | 3 | 1 | 0 |

TABLE XX A Comparison of the Truog Laboratory Method and the Illinois Phosphate Test

| Illinois Phosphate Test | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | Over 80 |
|---|---|---|---|---|---|---|---|---|---|
| Low | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Doubtful | 3 | 4 | 2 | 0 | 2 | 0 | 0 | 1 | 1 |
| Medium | 2 | 40 | 16 | 3 | 0 | 0 | 0 | 0 | 0 |
| High | 0 | 22 | 36 | 45 | 22 | 13 | 7 | 3 | 1 |

TABLE XXI A Comparison of the Truog Laboratory Method and Spurway's Water-Soluble Phosphorus Method

| Spurway's Water-Soluble Phosphorus P. P. M. | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | Over 80 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 6 | 12 | 6 | 9 | 2 | 1 | 0 | 1 | 0 |
| 0.5 | 4 | 51 | 40 | 20 | 9 | 3 | 1 | 1 | 0 |
| 1.0 | 0 | 2 | 9 | 18 | 11 | 7 | 3 | 1 | 2 |
| 2.0 | 0 | 0 | 1 | 1 | 1 | 2 | 3 | 0 | 0 |
| 3.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

TABLE XXII Comparison of Buffered and Unbuffered Extracting Solutions of the Truog Laboratory Method

P. P. M.

| Plat | Treatment | Unbuffered | Buffered | Plat | Treatment | Unbuffered | Buffered |
|---|---|---|---|---|---|---|---|
| Mankowski | | | | Demerest | | | |
| 201 | 100#$NaNO_3$<br>No A. P. | 29.8 | 19.6 | Check | | 24.1 | 27.2 |
| 202 | 100#$NaNO_3$<br>100#KCl<br>200#A.P. | 37.6 | 26.2 | 501 | 375#<br>2-16-6 | 26.6 | 30.3 |
| 203 | 100#$NaNO_3$<br>100#KCl<br>400#A.P. | 65.7 | 50.0 | 502 | 750#<br>2-16-6 | 54.8 | 59.5 |
| 204 | 100#$NaNO_3$<br>100#KCl<br>600#A.P. | 38.9 | 32.1 | 503 | 1500#<br>2-16-6 | 67.4 | 69.7 |
| 205 | 100#$NaNO_3$<br>100#KCl<br>800#A.P. | 54.5 | 45.5 | | | | |
| Elsby | | | | Bird | | | |
| 1 | Check | 42.1 | 40.1 | 1 | Check | 55.7 | 51.7 |
| 2 | 250#4-16-8 | 39.9 | 35.1 | 2 | 250#4-16-8 | 44.7 | 48.0 |
| 3 | 500#4-16-8 | 47.5 | 44.4 | 3 | 500#4-16-8 | 34.8 | 36.9 |
| 4 | 750#4-16-8 | 68.9 | 23.5 | 4 | 750#4-16-8 | 33.6 | 35.0 |
| 5 | 1000#4-16-8 | 45.5 | 36.0 | 5 | 1000#4-16-8 | 48.2 | 52.6 |
| 6 | 1500#4-16-8 | 44.2 | 54.0 | 6 | 1500#4-16-8 | 61.7 | 63.2 |
| 7 | 2000#4-16-8 | 62.0 | 72.2 | 7 | 2000#4-16-8 | 46.4 | 51.1 |
| Peeble | | | | Griswold | | | |
| 201 | 100#$NaNO_3$<br>100#KCl<br>Check | 21.8 | 24.4 | 201 | 67#$NaNO_3$<br>133#KCl<br>0 A. P. | 35.8 | 29.2 |
| 202 | 100#$NaNO_3$<br>100#KCl<br>200#A.P. | 22.2 | 25.8 | 202 | 67#$NaNO_3$<br>133#KCl<br>200#A.P. | 43.5 | 41.3 |
| 208 | 100#$NaNO_3$<br>100#KCl<br>400#A.P. | 39.7 | 36.3 | 203 | 67#$NaNO_3$<br>133#KCl<br>400#A.P. | 67.8 | 58.5 |
| 204 | 100#$NaNO_3$<br>600#A.P.<br>100#KCl | 37.3 | 34.5 | 204 | 67#$NaNO_3$<br>133#KCl<br>600#A.P. | 54.3 | 52.3 |
| 205 | 100#$NaNO_3$<br>100#KCl<br>800#A.P. | 68.6 | 68.5 | 205 | 67#$NaNO_3$<br>133#KCl<br>800#A.P. | 72.0 | 68.9 |
| Hopfer | | | | Kalamazoo | | | |
| 602 | Check | 33.9 | 13.7 | Check | | 31.9 | 34.8 |
| 601 | 250#2-16-6 | 30.0 | 19.4 | | 100A.P. | 31.9 | 21.6 |
| 603 | 500#2-16-6 | 40.7 | 30.3 | | 300A.P. | 28.5 | 20.9 |
| 605 | 1000#2-16-6 | 77.3 | 66.5 | | 500A.P. | 33.8 | 25.1 |
| Orr | | | | Kewaunee | | | |
| 601 | Check | 38.4 | 38.8 | Check | | 21.1 | 8.0 |
| 602 | 250#2-16-6 | 34.8 | 34.7 | P.& L. | | 26.5 | 18.7 |
| 604 | 500#2-16-6 | 36.0 | 39.7 | | | | |
| 605 | 1000#2-16-6 | 45.9 | 47.8 | | | | |

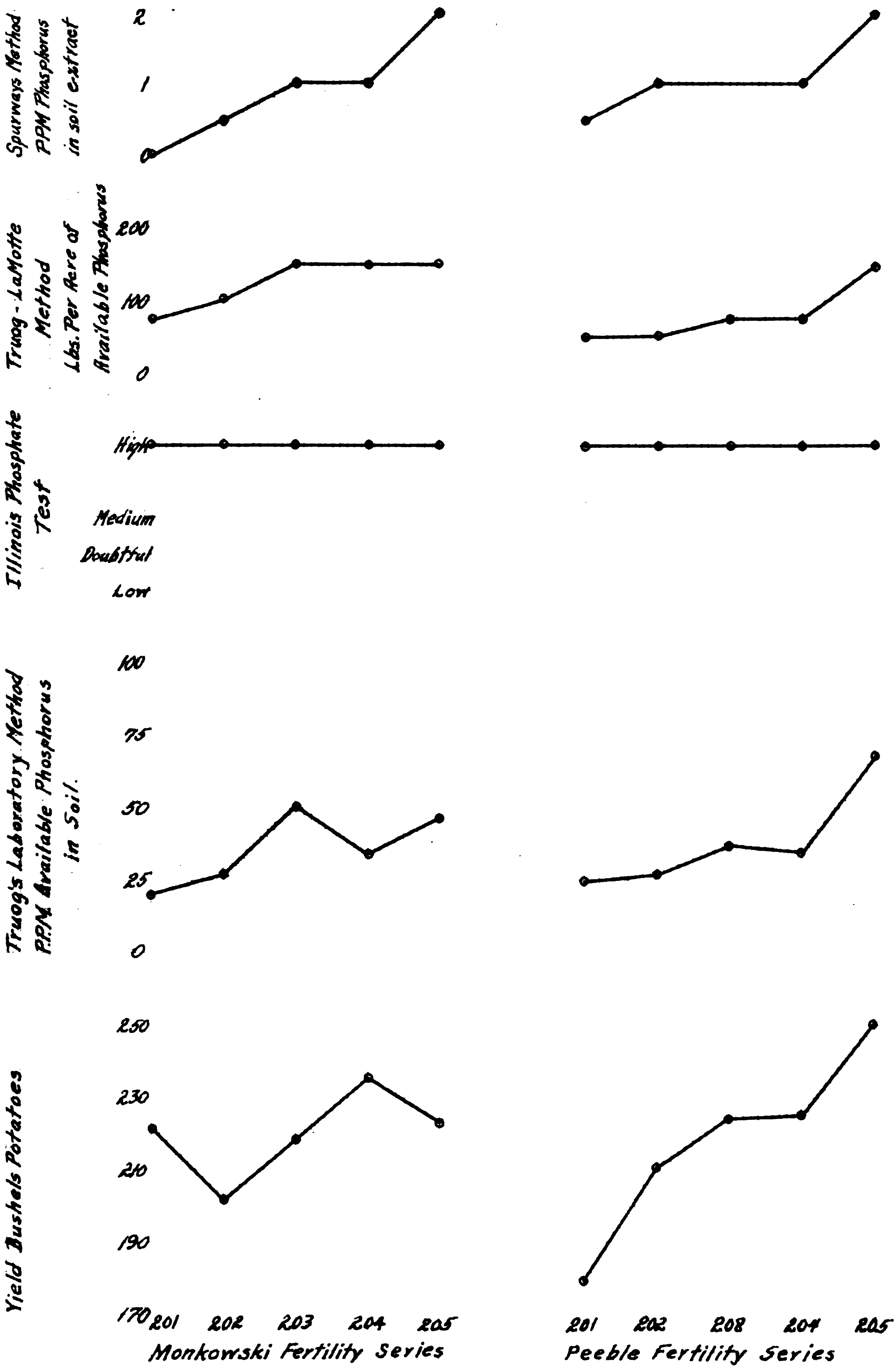
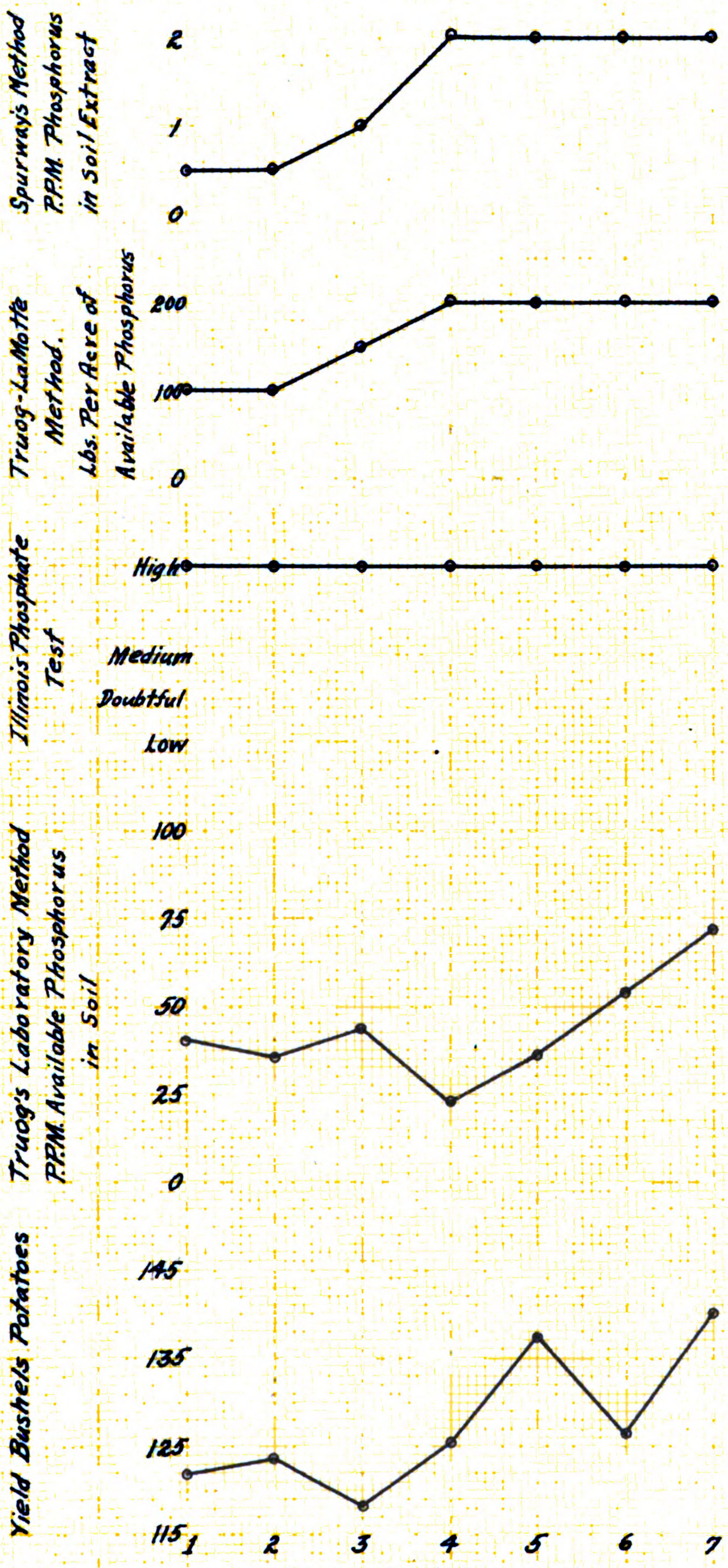

Spurways Method PPM Phosphorus in soil extract
2
1
0
Truog - LaMotte Method Lbs. Per Acre of Available Phosphorus
200
100
0
Illinois Phosphate Test
High
Medium
Doubtful
Low
Truog's Laboratory Method P.P.M. Available Phosphorus in Soil.
100
75
50
25
0
Yield Bushels Potatoes
250
230
210
190
170
201
202
203
204
205
Monkowski Fertility Series
201
202
203
204
205
Peeble Fertility Series

Figure 1



Elsby Fertility series
Figure 2

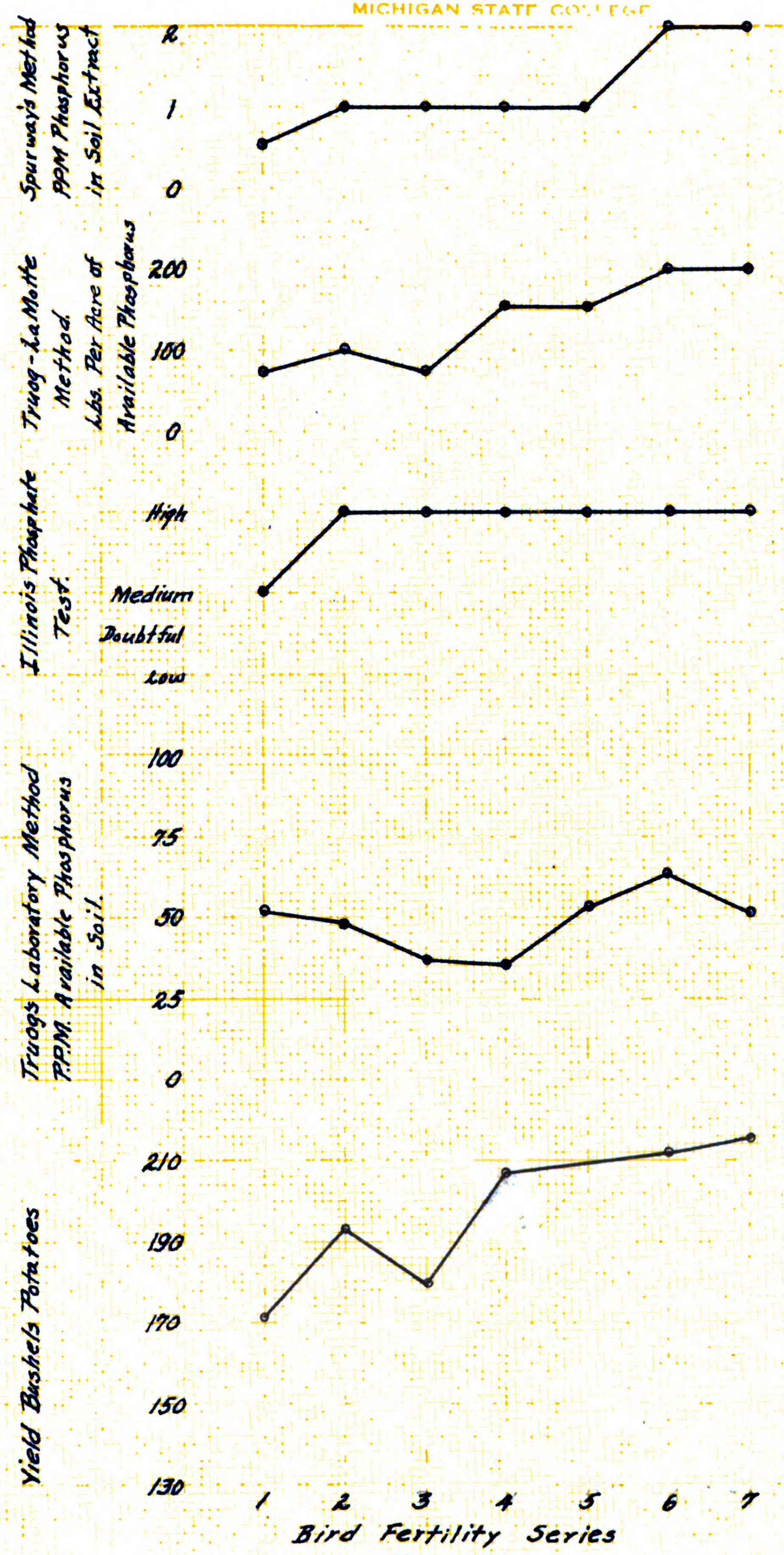

Spurway's Method
PPM Phosphorus
in Soil Extract
2
1
0
Truog-LaMotte
Method
Lbs. Per Acre of
Available Phosphorus
200
100
0
Illinois Phosphate
Test.
High
Medium
Doubtful
Low
Truogs Laboratory Method
P.P.M. Available Phosphorus
in Soil.
100
75
50
25
0
Yield Bushels Potatoes
210
190
170
150
130
1
2
3
4
5
6
7
Bird Fertility Series

Figure 3

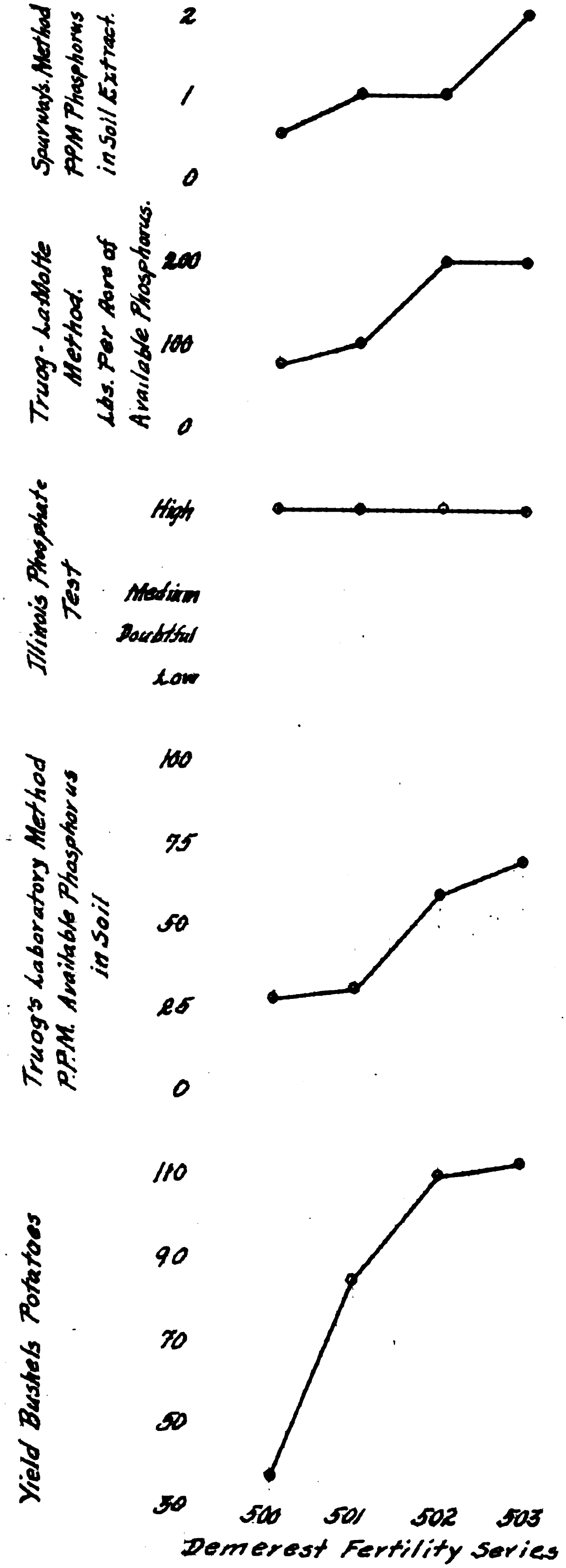

Spurway's Method
PPM Phosphorus
in Soil Extract.
2
1
0
Truog - LaMotte
Method.
Lbs. Per Acre of
Available Phosphorus.
200
100
0
Illinois Phosphate
Test
High
Medium
Doubtful
Low
Truog's Laboratory Method
P.P.M. Available Phosphorus
in Soil
100
75
50
25
0
Yield Bushels Potatoes
110
90
70
50
30
500
501
502
503
Demerest Fertility Series

Figure4

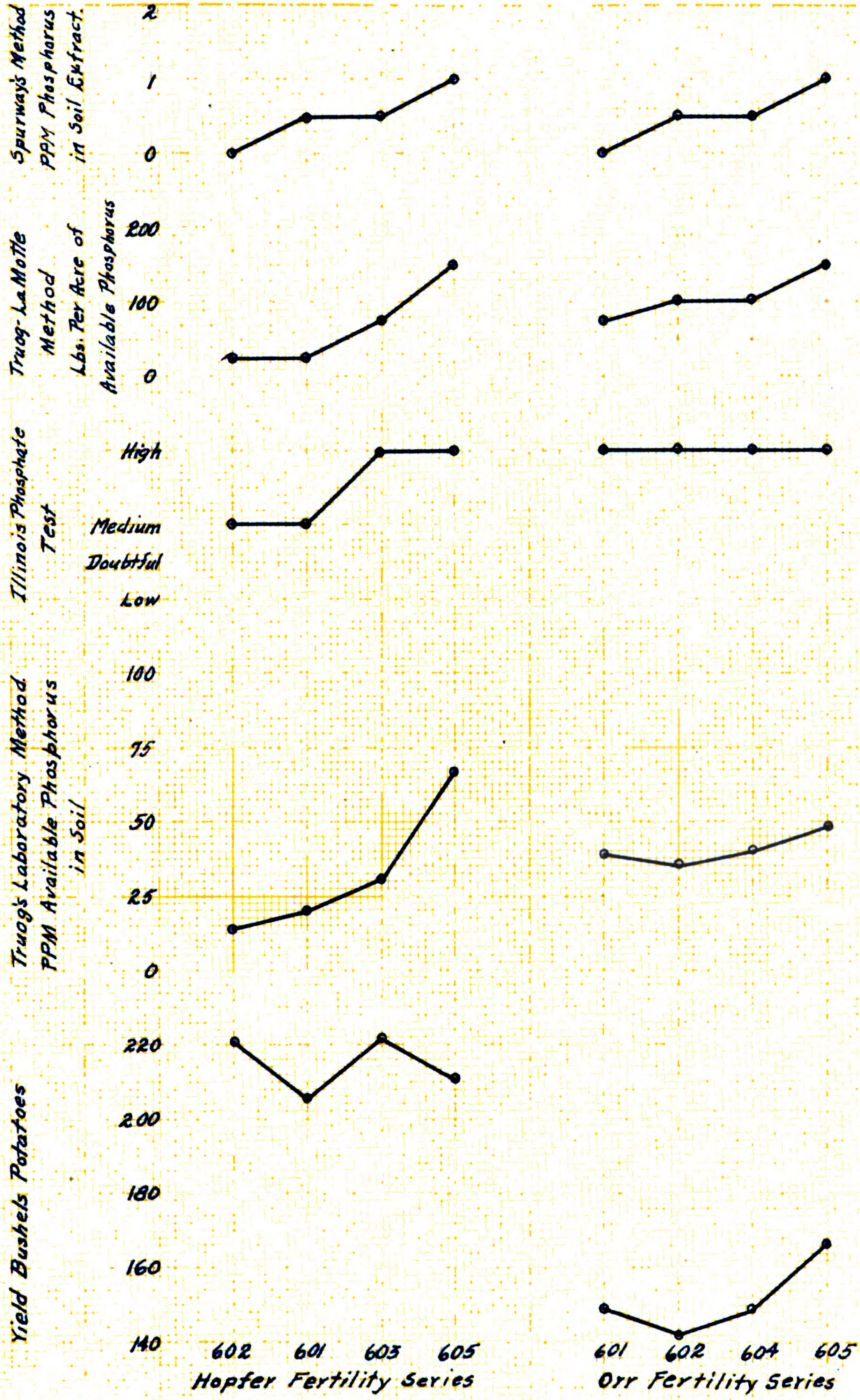

Spurway's Method PPM Phosphorus in Soil Extract
2
1
0
Truog-LaMotte Method Lbs. Per Acre of Available Phosphorus
200
100
0
Illinois Phosphate Test
High
Medium
Doubtful
Low
Truog's Laboratory Method PPM Available Phosphorus in Soil
100
75
50
25
0
Yield Bushels Potatoes
220
200
180
160
140
602
601
603
605
601
602
604
605
Hopfer Fertility Series
Orr Fertility Series

Figure 5.

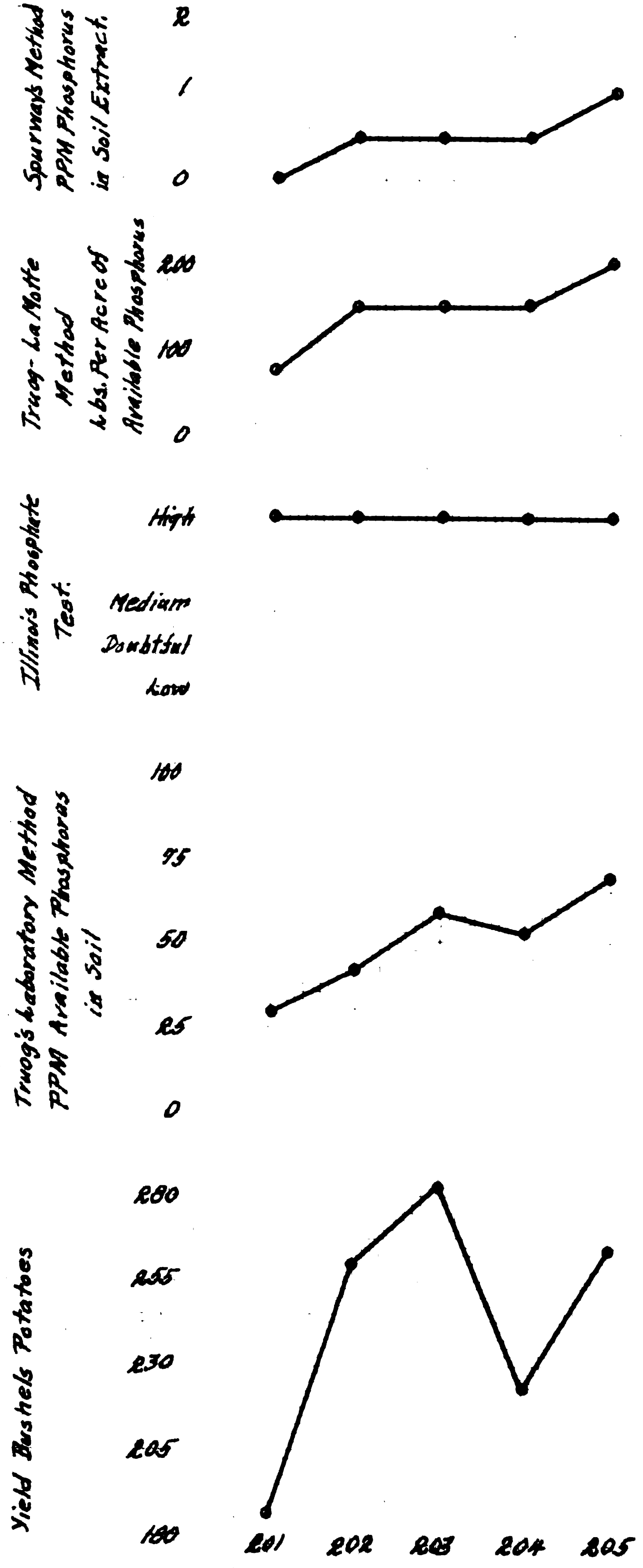

Spurways Method PPM Phosphorus in Soil Extract
2
1
0
Truog-La Motte Method Lbs. Per Acre of Available Phosphorus
200
100
0
Illinois Phosphate Test.
High
Medium
Doubtful
Low
Truog's Laboratory Method PPM Available Phosphorus in Soil
100
75
50
25
0
Yield Bushels Potatoes
280
255
230
205
180
201
202
203
204
205
Griswold Fertility Series

Figure 6.

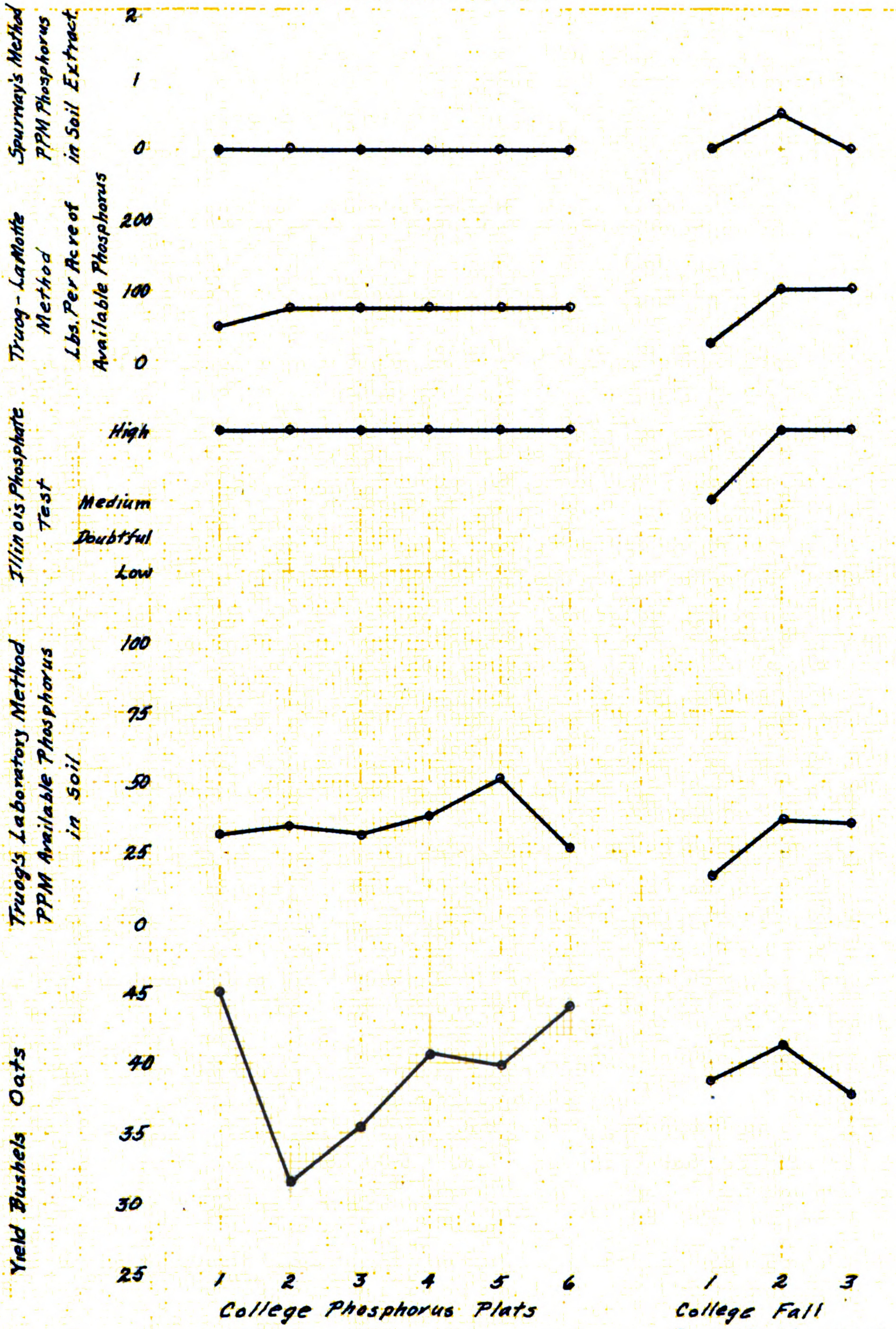
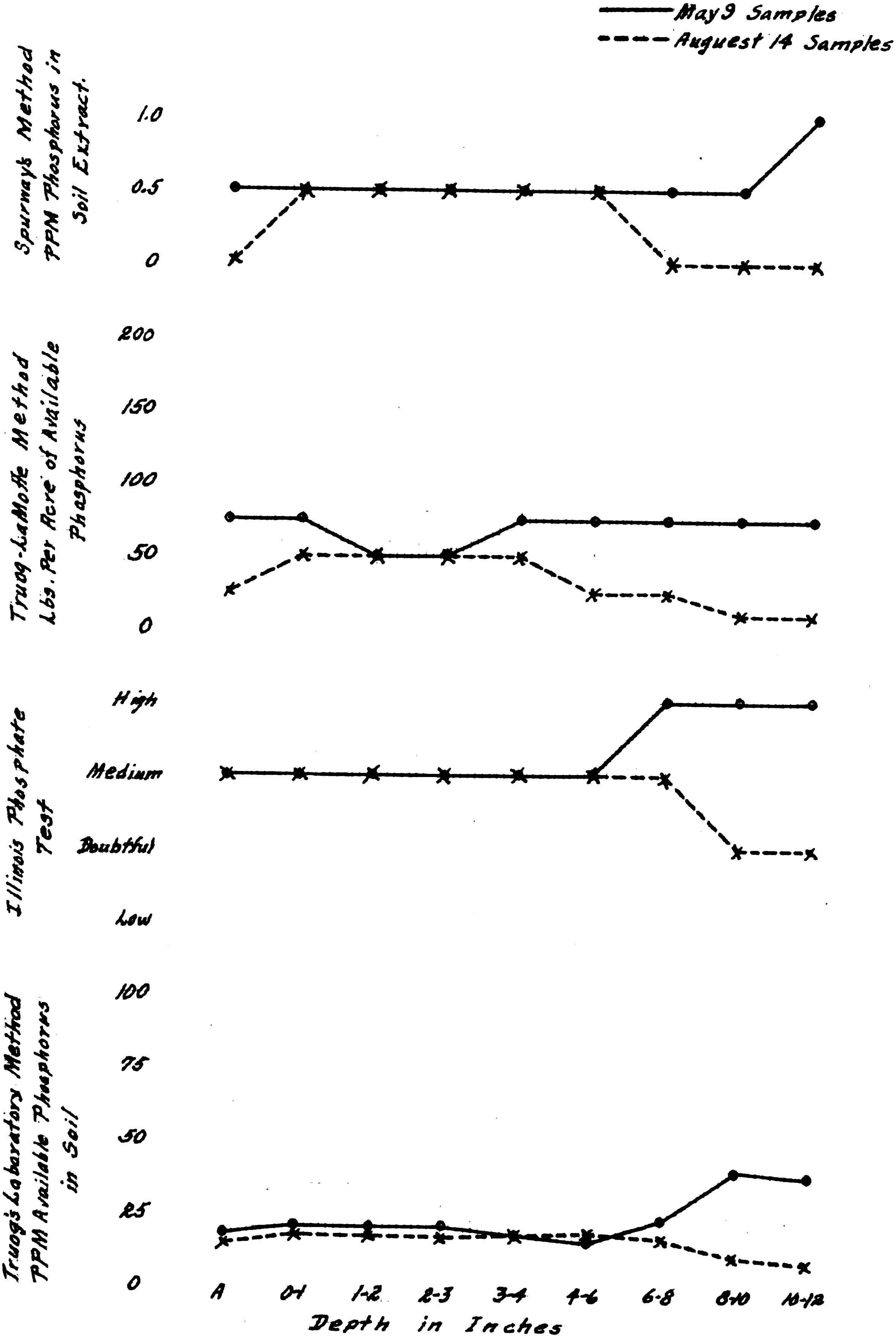
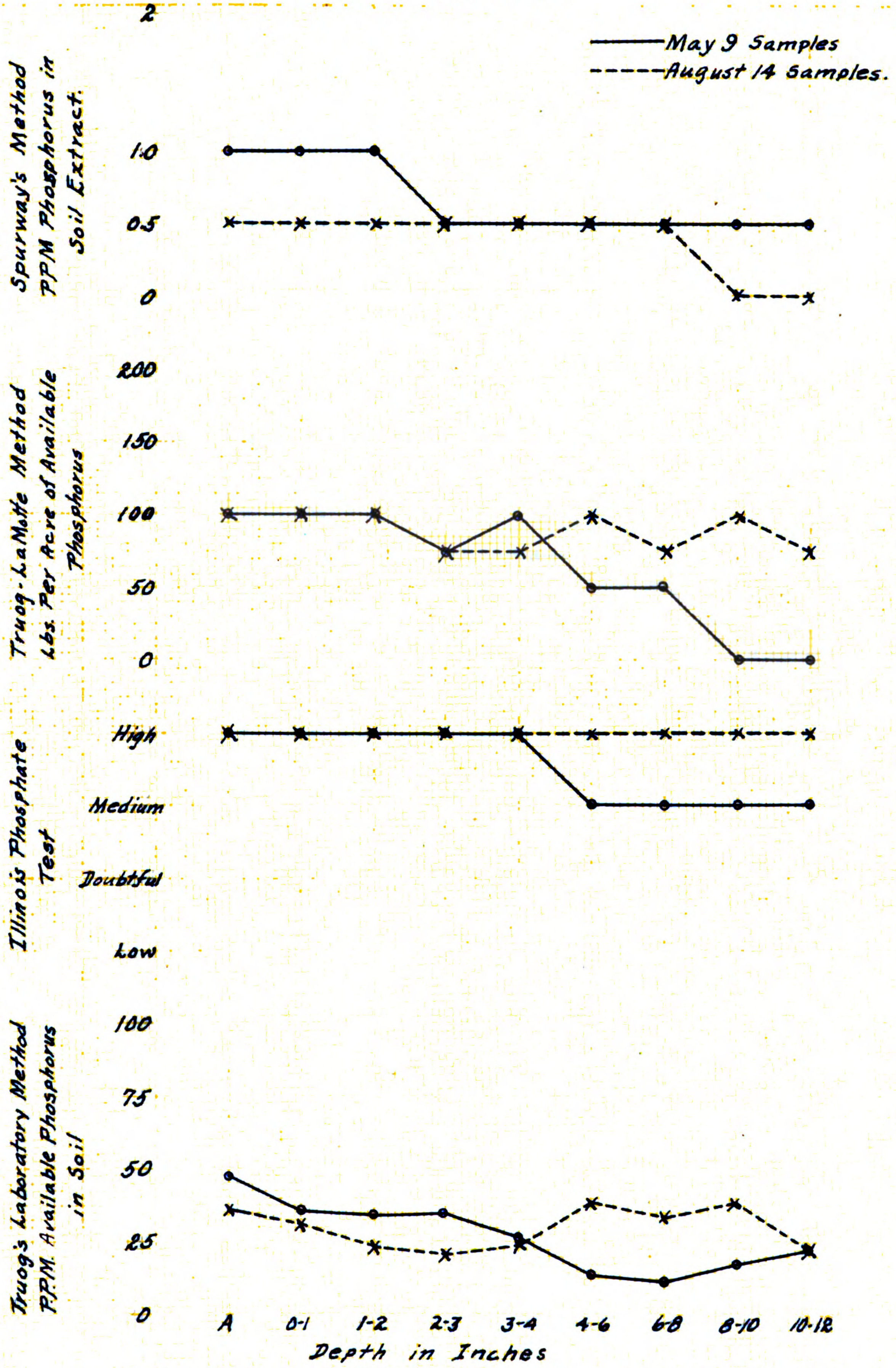

Spurway's Method
PPM Phosphorus
in Soil Extract
2
1
0
Truog-LaMotte
Method
Lbs. Per Acre of
Available Phosphorus
200
100
0
Illinois Phosphate
Test
High
Medium
Doubtful
Low
Truog's Laboratory Method
PPM Available Phosphorus
in Soil
100
75
50
25
0
Yield Bushels Oats
45
40
35
30
25
1
2
3
4
5
6
College Phosphorus Plats
1
2
3
College Fall
Fertillization Plats

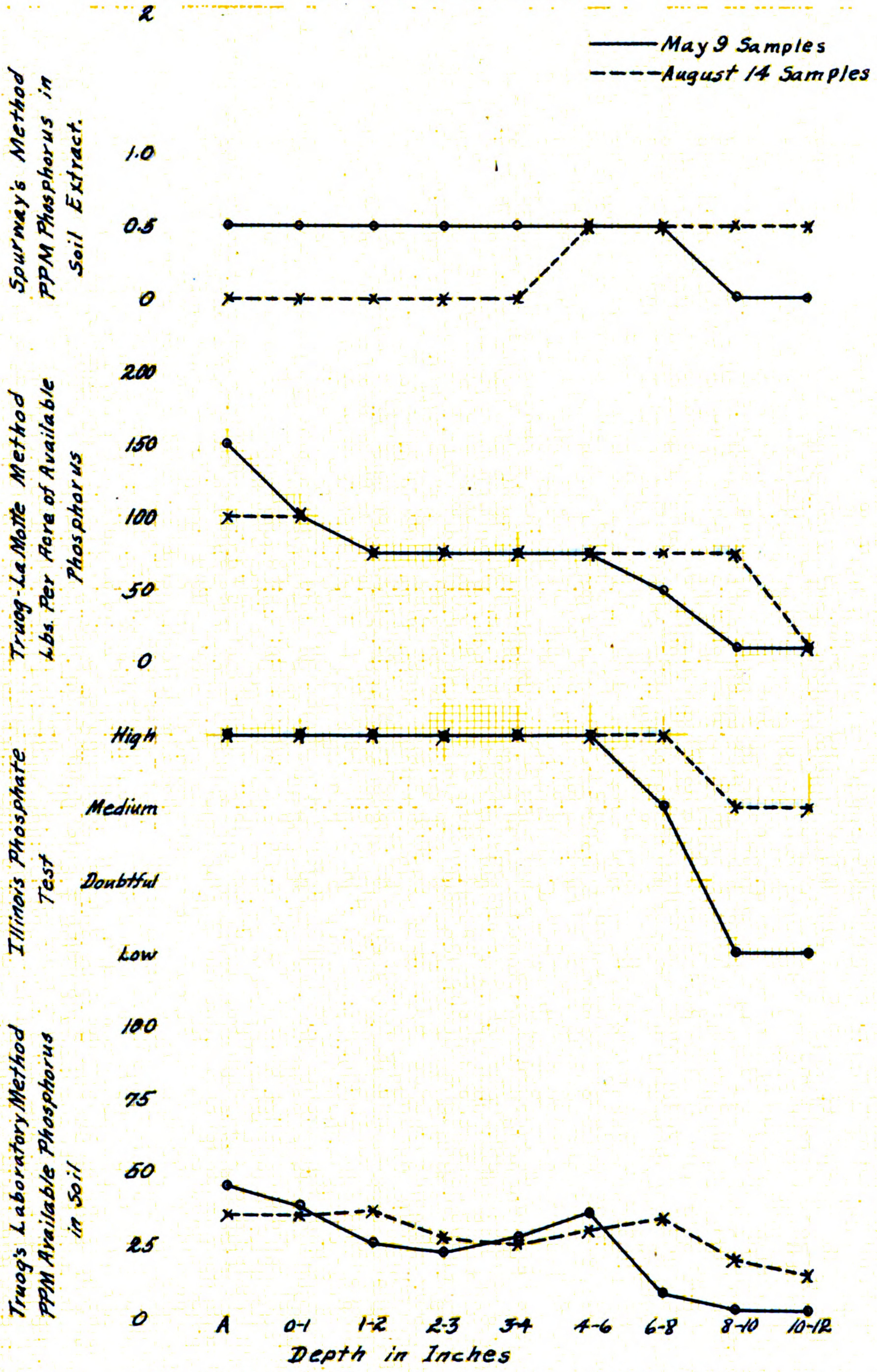
Figure 7



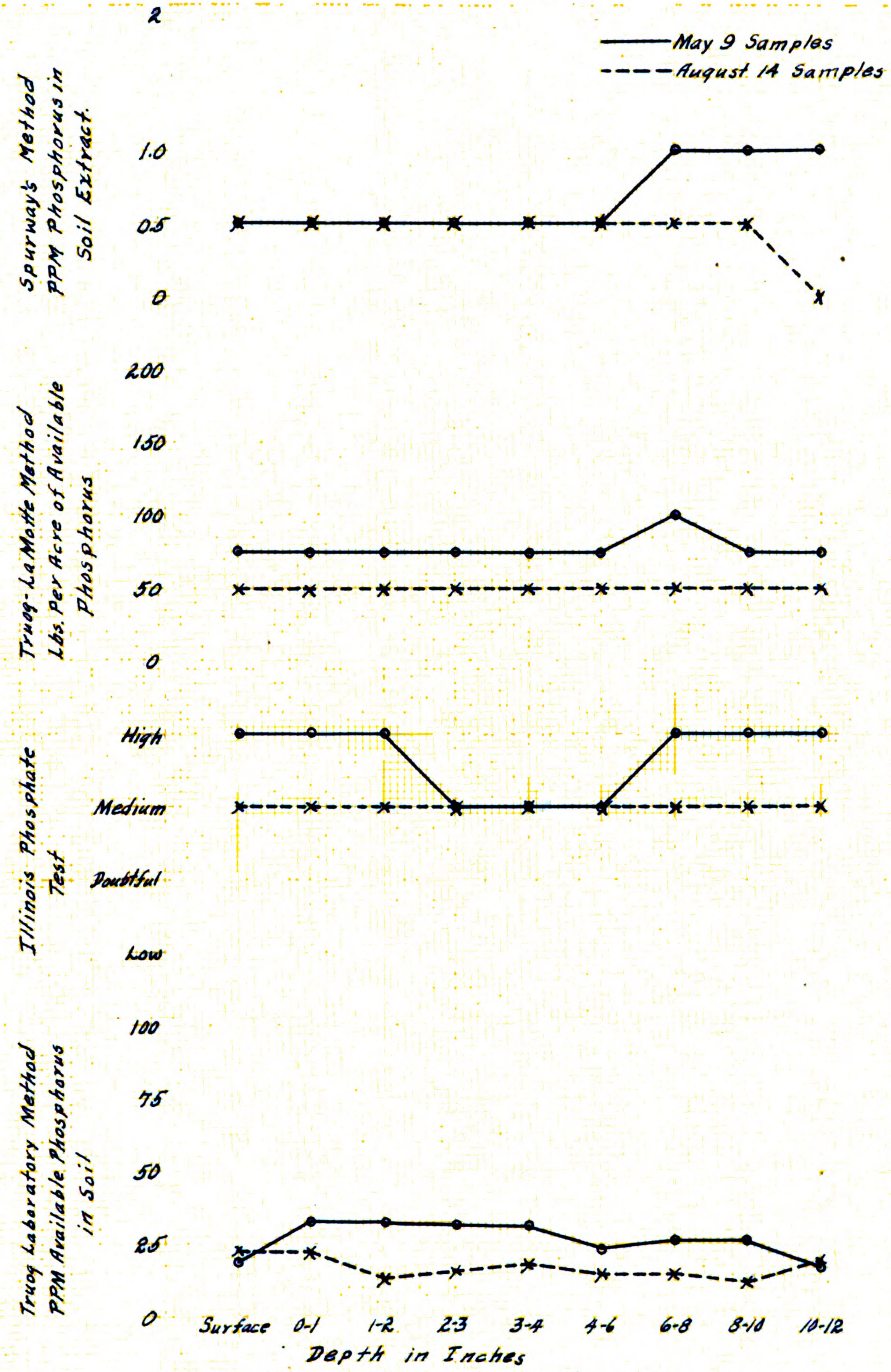
Depth Samples from College Fall Fertillization Plats
Samples Taken on Different Dates Series 1F
Figure 8.



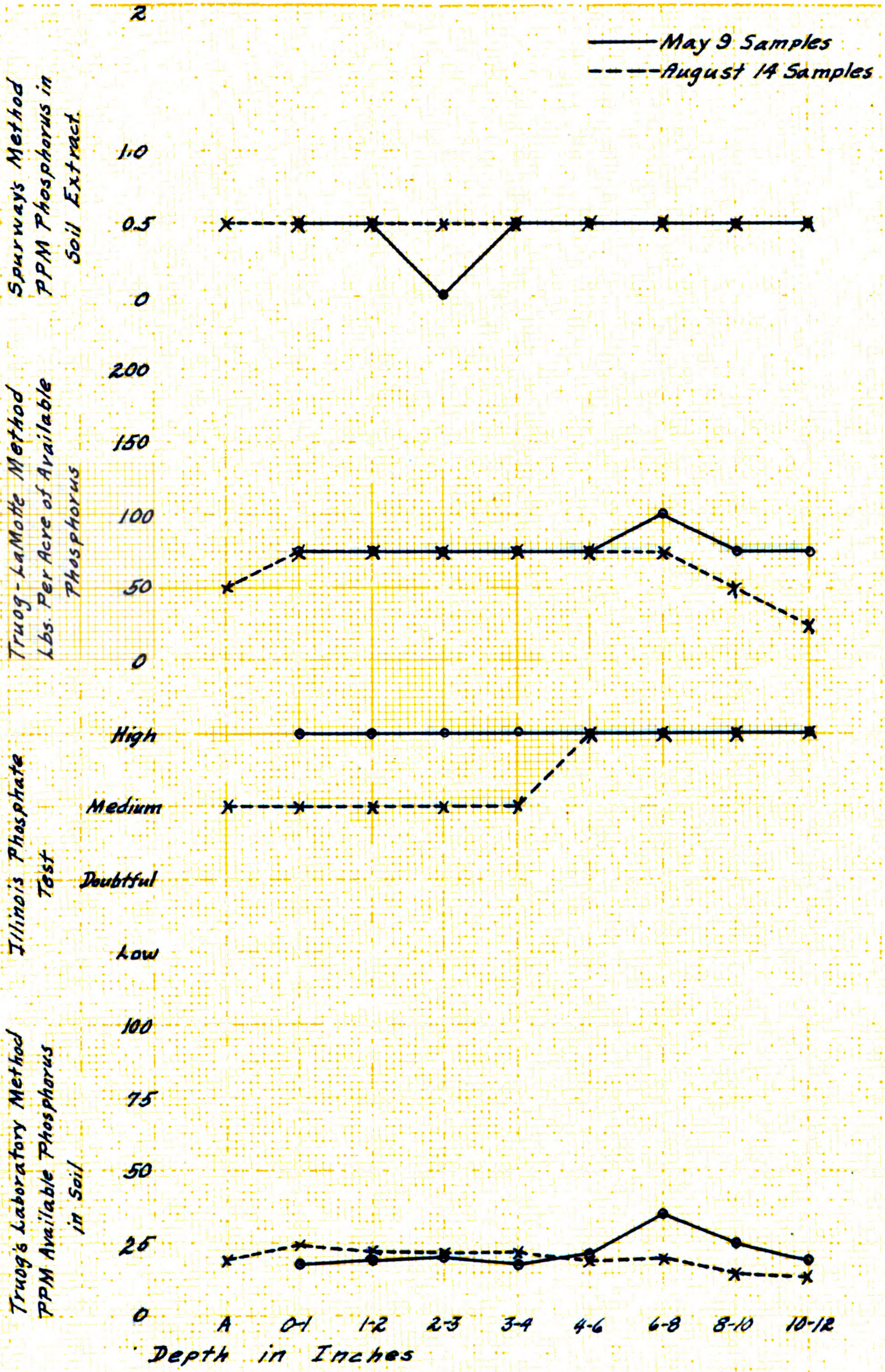
Depth Samples Taken from College Fall Fertillization Plats
Samples Taken at Different Dates Series 2F
Figure 9.



Depth Samples Taken from College Fall Fertilization Plots
Samples Taken at Different Depths Series 3F.
Figure 10.



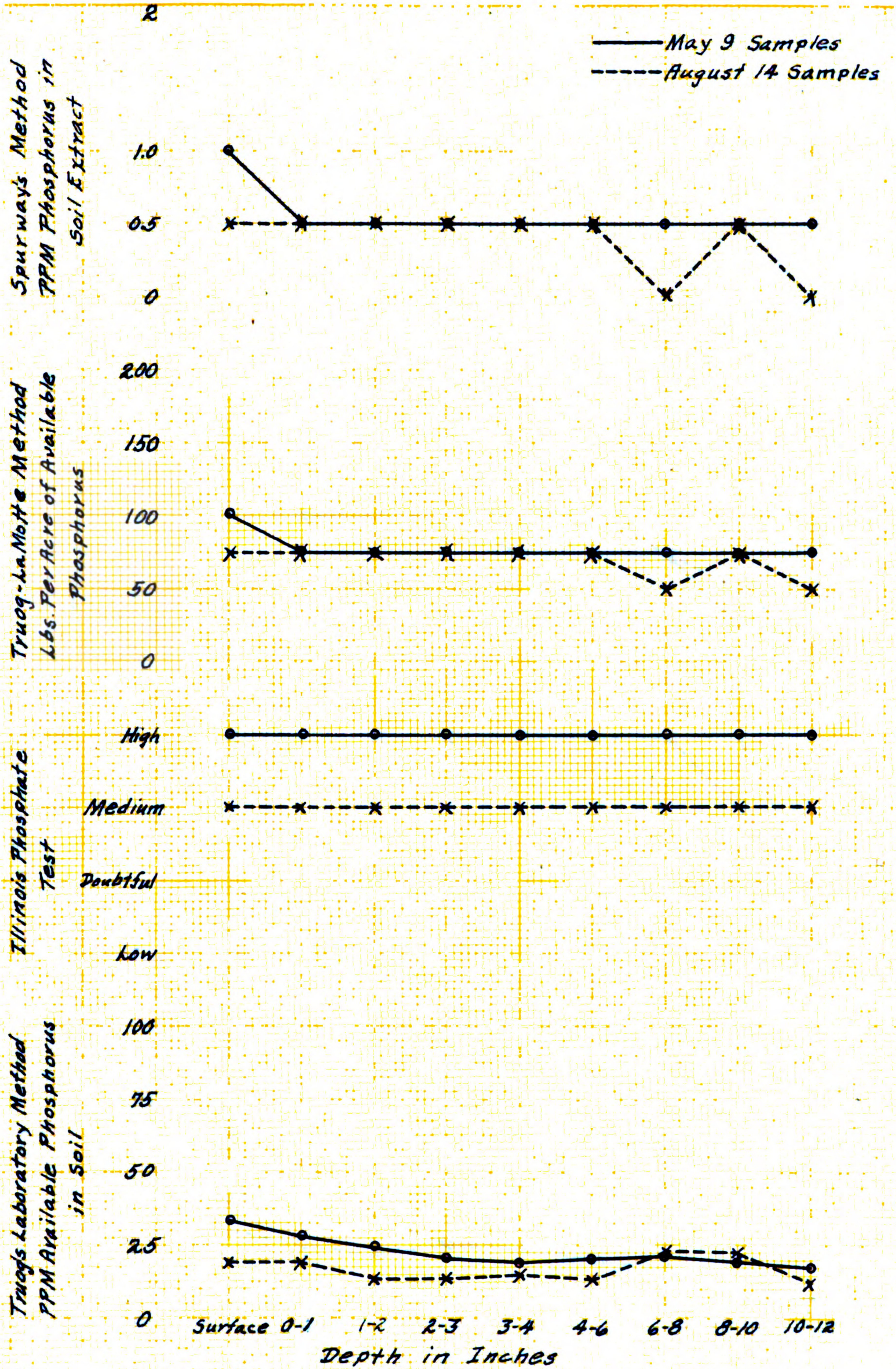
Depth Samples from College Phosphorus Plats.
Series 1P
Figure 11.



Depth Samples from College Phosphorus Plats

Series 2P

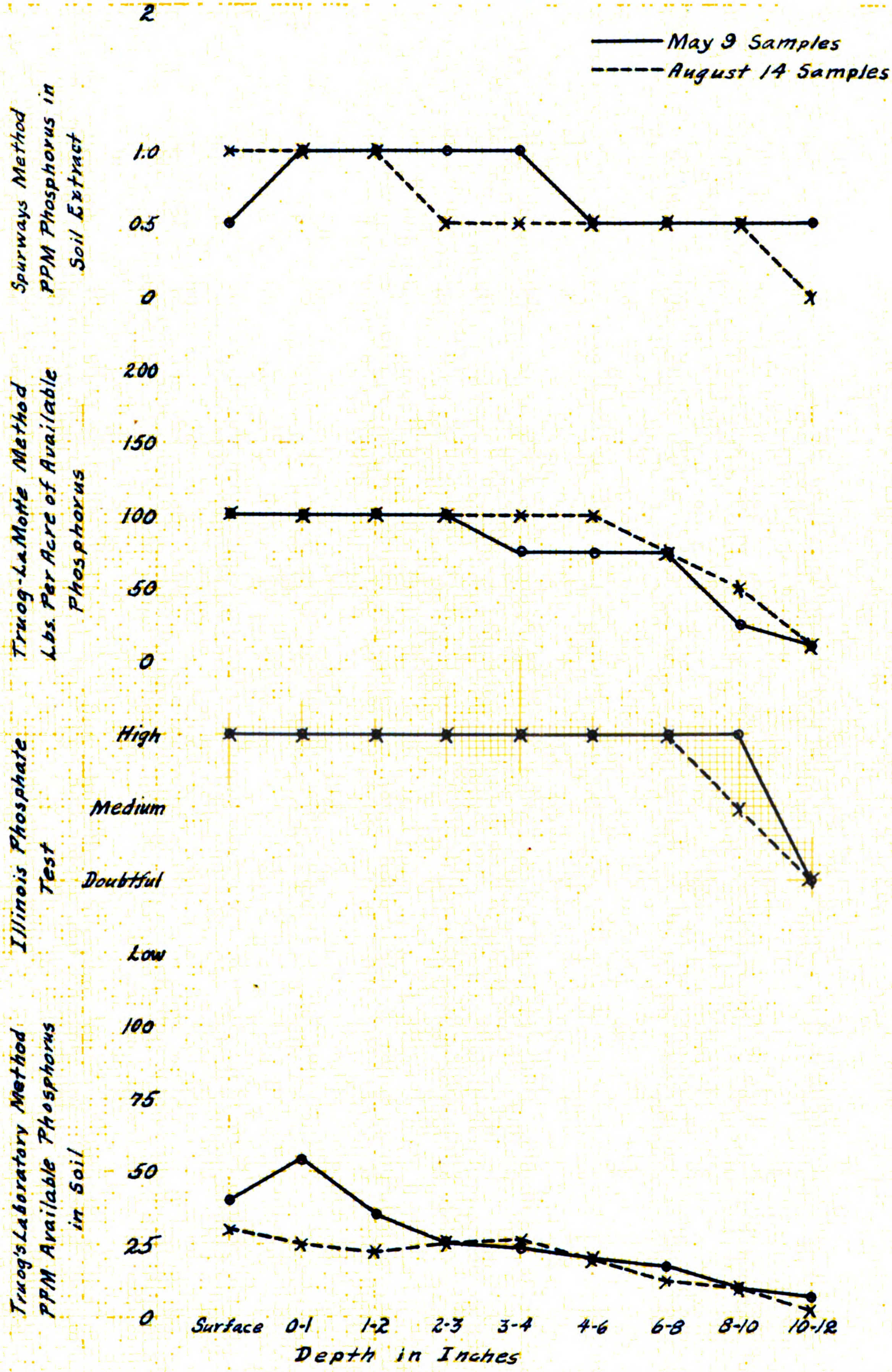
Figure 12



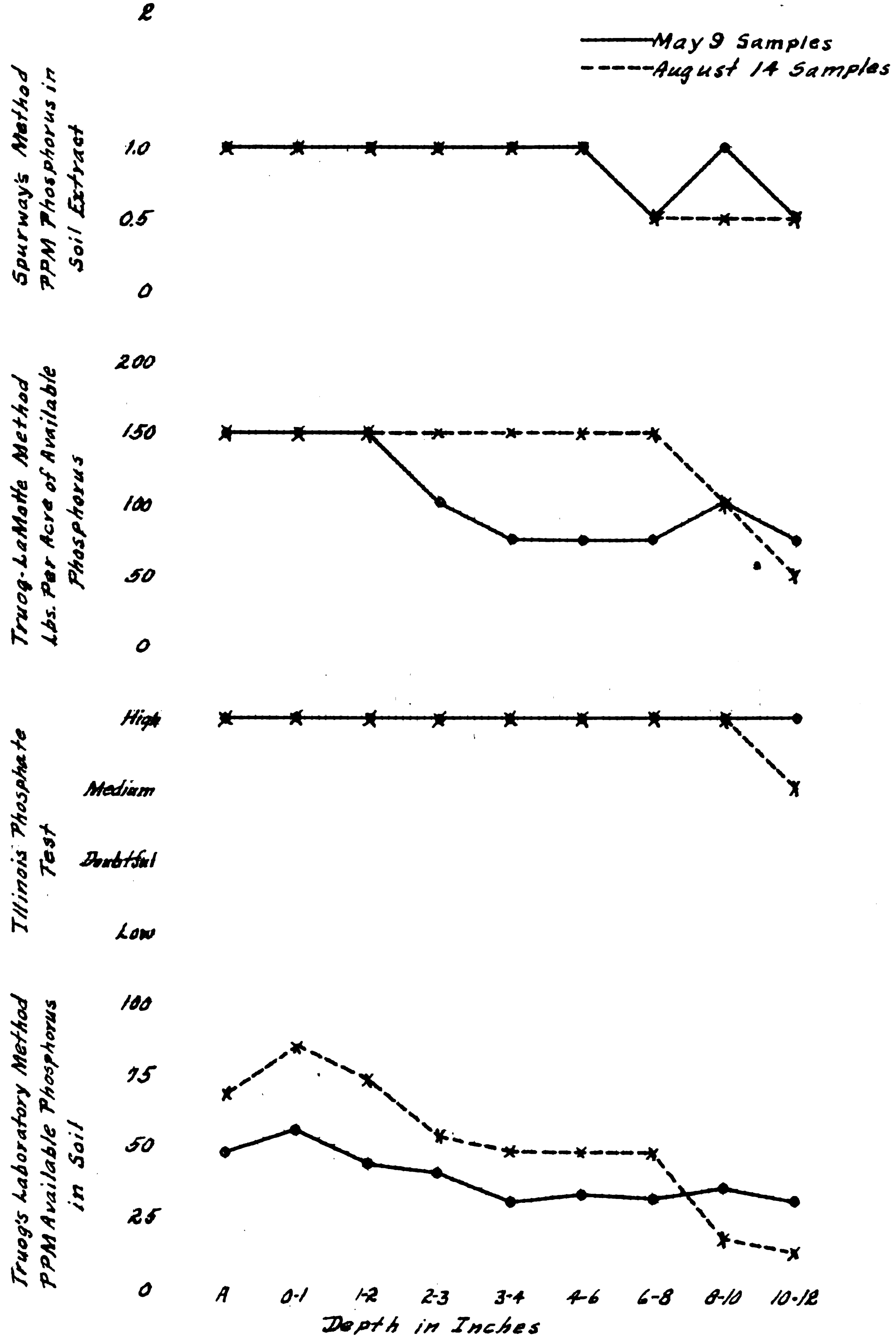
Depth Samples from College Phosphorus Plats

Series 3P.

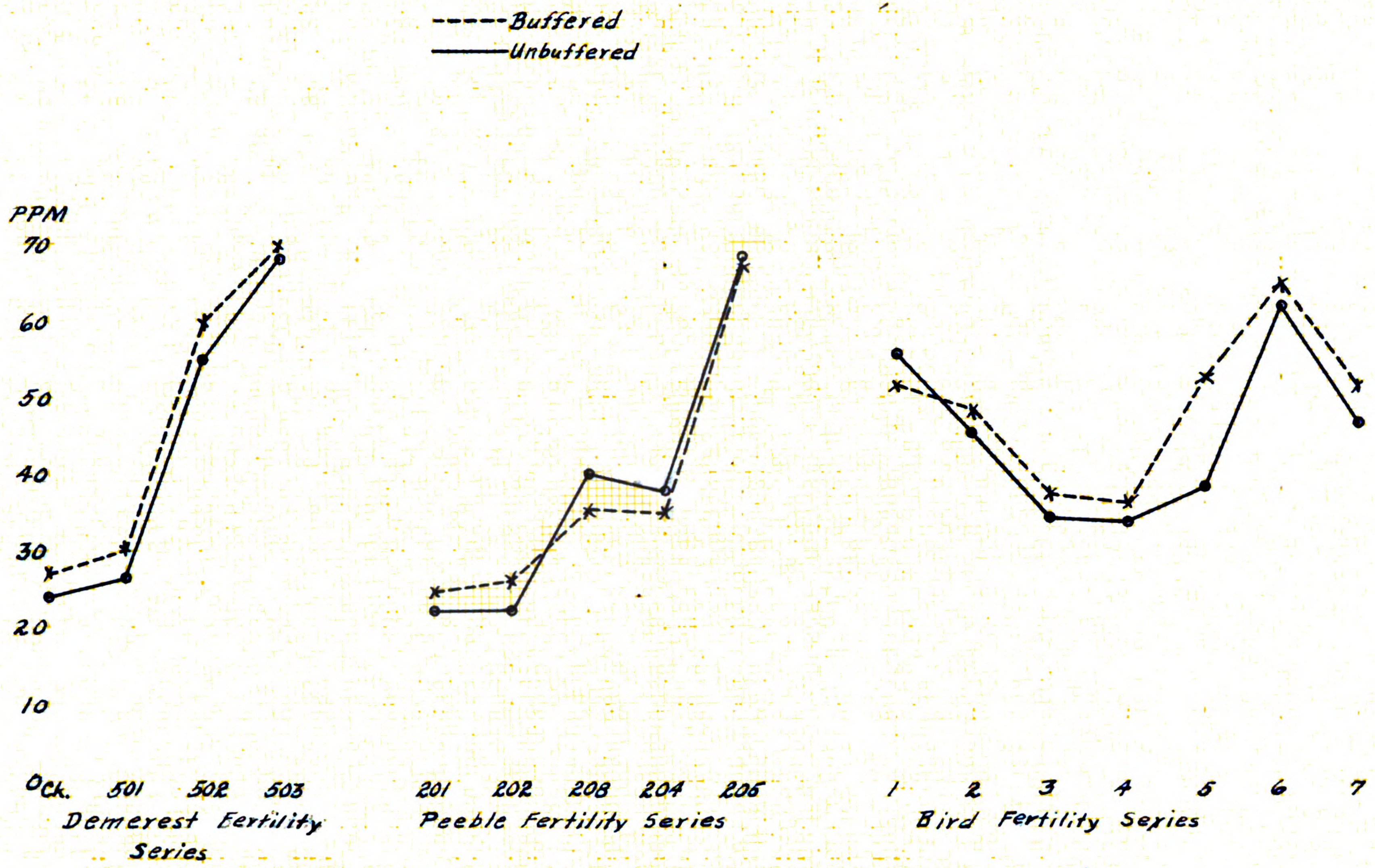
Figure 13



Depth Samples Taken from College Phosphorus Plats
Series 4P
Figure 14

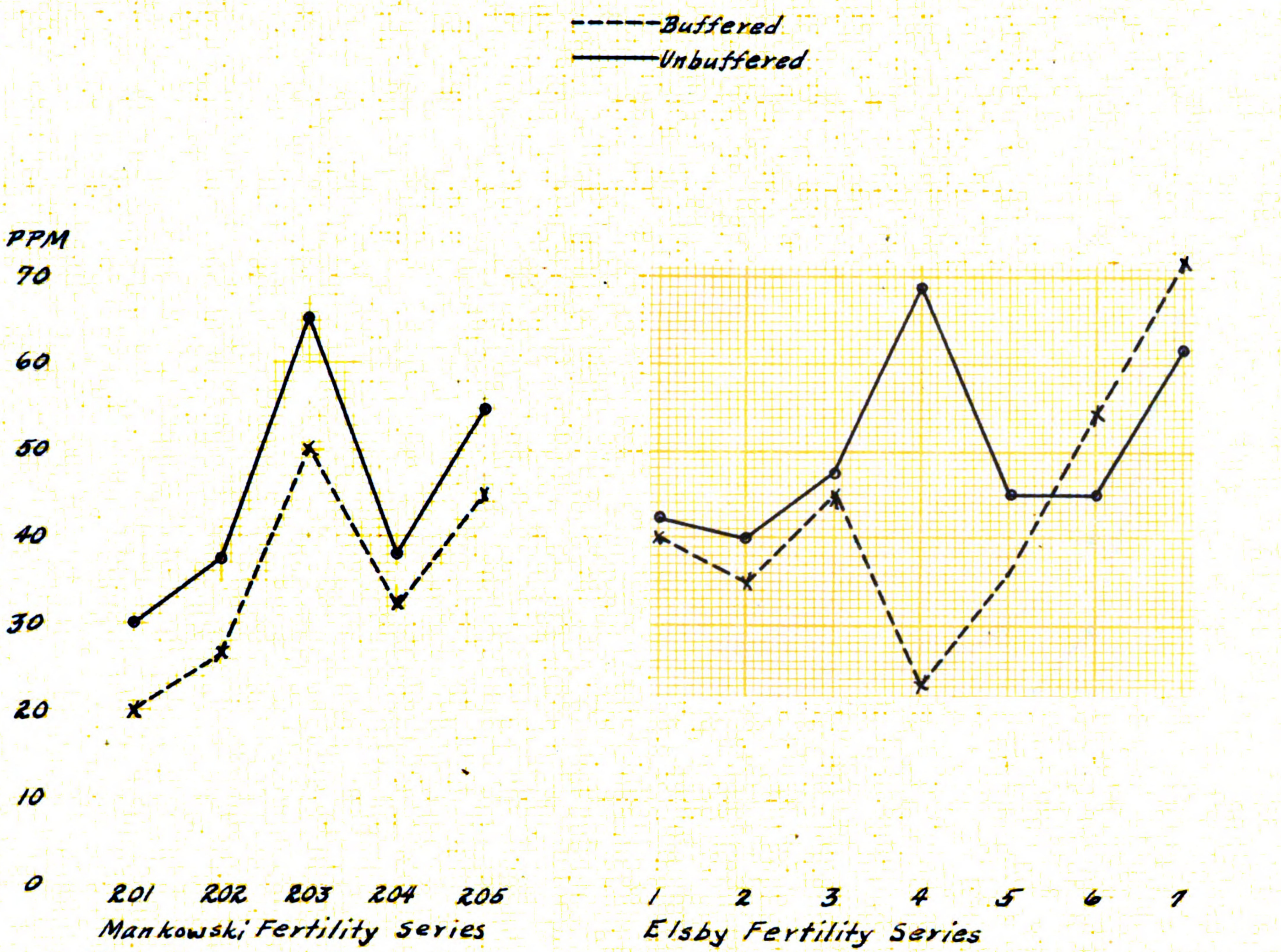


Depth Samples from College Phosphorus Plots
Series 5P
Figure 15.



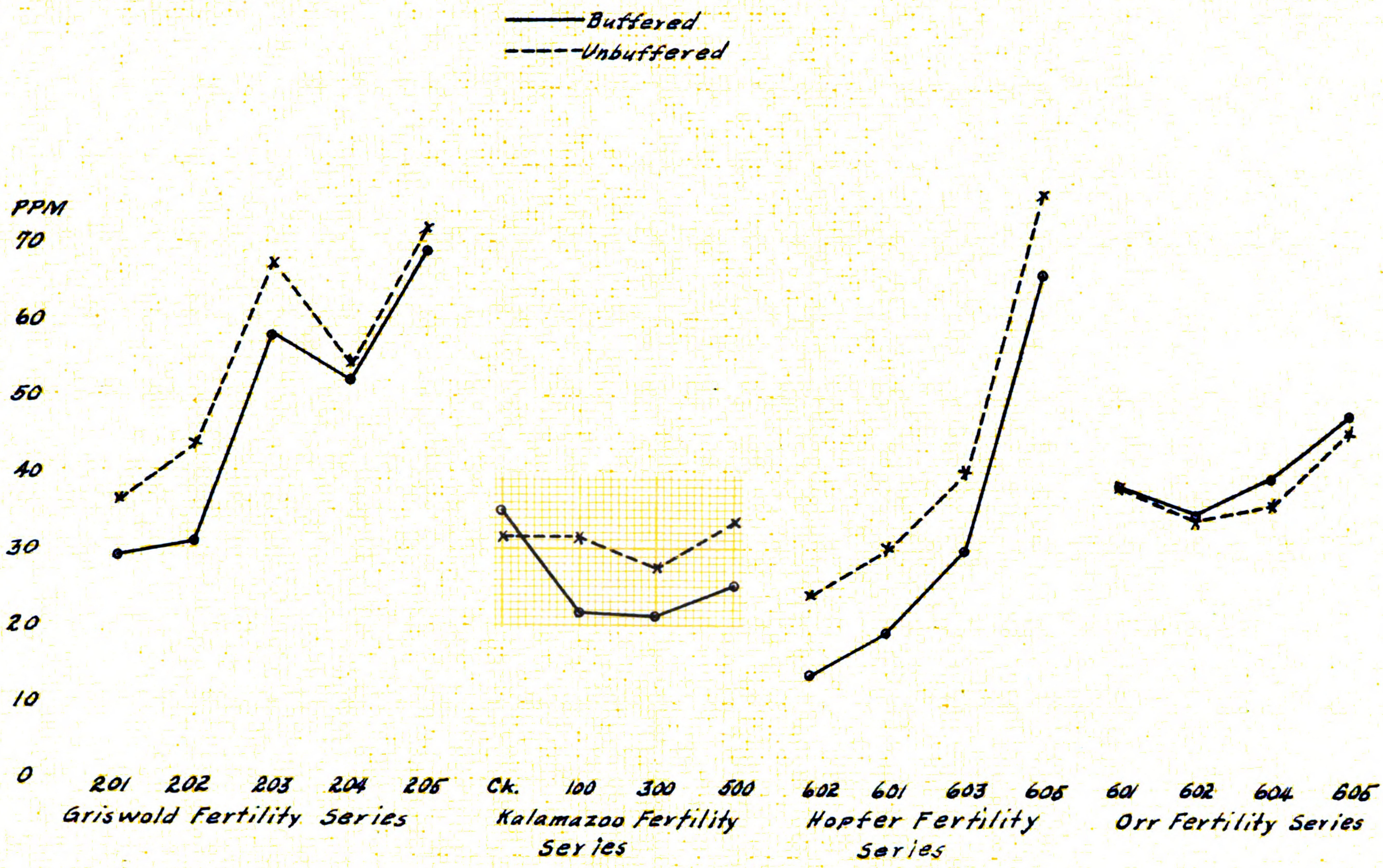
Comparison of Use of Buffered and Unbuffered $H_2SO_4$ Extracting Solutions

Figure 16



Comparison of Use of Buffered and Unbuffered $H_2SO_4$ Extractin Solutions

Figure 17



Comparison of Use of Buffered and Unbuffered $H_2SO_4$ Extracting Solutions

Figure 18