THE RELATION BETWEEN FORMS OF SOIL PHOSPHORUS AND RESPONSE OF ALFALFA AND SMALL GRAIN TO ADDED PHOSPHATE

by

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INTRODUCTION

In the earlier studies of soil fertility and plant nutrition workers sought to determine the amounts of nutrients in the soil by a total chemical analysis. It was found, however, that no practical correlations could be drawn between the total amount of nutrients and the requirements of plants. From this early concept there was a decided reaction to the other extreme--as exemplified by Dyer's citric acid soluble phosphorus (15). This was the concept of measuring quantitatively that portion of the total amounts of nutrients which plants could actually absorb. Dyer's method allowed rather broad correlations with productivity, but its success was temporary since on many soils it failed in the determination of specific correlations and separated only a minute quantity of what is now termed "acid-soluble" phosphorus.

The use of carbonic acid as an extractant simulating the soil solution in the region of the root hairs is another attempt to measure the amounts of phosphorus available to plants. It has proven successful on the highly alkaline soils of the western states, but on acid soils this method has generally been unsatisfactory.

Numerous dilute solutions of strong acids have been presented as separating the "available" fractions of phosphorus. Among these are 0.1 N HNO_3, 0.1 N HCl and the widely used .002 N H_2SO_4 of Truog (27). However, it is believed by Bray (4) and others that this concept of availability is erroneous. Usually, a plant nutrient occurs in more than one form in the soil, with each form contributing to the nutrition of plants. The acid-soluble fraction is but one of the forms of the soil phosphorus. The most recent concept calls for the use of extractants designed to remove the various forms selectively or in combination. Bray and Kurtz (7) have recently presented analytical methods for the determination of the acid-soluble, adsorbed and organic fractions of the soil phosphorus developed from studies on Illinois soils.

The mere determination of the fractions is useless until their amounts are calibrated by observation on the specific responses of crops to added phosphate on various soil types. The objective of this investigation was, therefore, to analyze, according to these methods, a number of Michigan soils showing high and low response to added phosphate, to attempt correlation of the amounts of the various fractions with crop responses and to study the relationships of the fractions with various soil properties. It was hoped that the results might assist in evaluating further use of the methods for determining soil management practices under Michigan conditions.

REVIEW OF LITERATURE

Acid-Soluble Phosphorus

In the literature, the term "forms" of soil phosphorus is used interchangeably between actual phosphorus compounds and the fractions soluble in a given extractant. The most commonly accepted fraction is the "easily acid-soluble" phosphorus of Truog (27), which is soluble in .002 N sulfuric acid buffered to pH 3. Bray (5) states that this fraction usually represents a minor part of the total phosphorus and in Illinois soils is generally present to the extent of 8 to 100 pounds per acre. It is more readily available to plants than the difficultly soluble fraction--that which is not soluble to any important extent in the acid solvents employed in the commonly used soil tests--but it may vary in degree of availability from soil to soil because of differences in the chemical nature of forms included in this fraction. On Minnesota soils Rost and Pinckney (25) tested 112 check plot samples by Truog's method. They found that plots carrying 25 lb. or less of this fraction responded to superphosphate in sixty-nine per cent of the cases and in seventy-three per cent of the cases of those carrying between 26 and 50 lb. phosphorus.

Using acid extractants of pH 2 and pH 5 on Maryland soils, Fisher and Thomas (18) divided the inorganic soil phosphorus into (a) amorphous and finely divided crystalline phosphates of calcium, magnesium and manganese; (b) amorphous phosphates of aluminum and iron; (c) phosphorus adsorbed upon hydrous oxides and that present in the form of apatite. By placing proper values upon the phosphorus contained in each group it was found that analyses by this method placed 22 soils in practically the identical order of phosphorus requirements as that disclosed by pot tests.

A number of Kentucky soils were extracted with 25 different acid, base and salt solutions by Weeks and Karraker (30) in an effort to compare the usefulness of the solutions in measuring the availability of phosphorus in the soil. It was found that there was no best extractant. They believed that for the practical purpose of estimating the phosphate needs of soils, experience gained with the use of any one of the extractants on a given soil is of more importance than the extractant itself.

Fraps and Fudge (19) determined the solubility of phosphorus in 34 Texas soils of low basicity in 0.2 N nitric acid, 0.75 N hydrochloric acid, .002 N sulfuric acid and 0.52 N acetic acid in 10% sodium acetate. They state that none of the extractants give quantitative estimates of the quantity of phosphoric acid which is, or may become available to plants, though there may be a significant relation between the quantity dissolved by the extractants and the quantity taken up by plants. The correlation coefficients for the relation between phosphoric acid removed by crops and that dissolved by solvents were much greater for the mineral acids, with the .002 N sulfuric acid giving the highest value. Comparison of the quantities of phosphoric acid dissolved by the weak solvents with those of total phosphoric acid showed that the major part of the phosphorus in those soils is in the form of iron, aluminum, organic and adsorbed phosphates.

Using a quick-test technique (1 gram of soil shaken with 0.7 N HCl for 10 minutes), Olson (21) found good correlations between amounts of phosphorus removed and crop response to added phosphate with corn, lespedeza and pimientos. Cotton did not give a comparable correlation. It was conjectured that the ability of the cotton to feed upon the adsorbed phosphorus caused this difference.

Adsorbed Phosphorus

Recently concepts of the available forms of phosphorus have been amplified and clarified by the general division of certain soil phosphates into the adsorbed fraction as well as the easily acid-soluble forms.

As early as 1936 Truog (28) stated that below pH 6.5 and especially below pH 6.0 there is very little calcium phosphate (acid-soluble) present unless recently supplied. Usually less than five per cent of the supply was in this form and he believed that phosphorus that may be measured as being readily available comes largely from basic iron phosphate and is small in amount.

Davis (10) found that much of the phosphorus retained at reactions below pH 6.5 is held differently when it is added as H_3PO_4 than it is when added as $Ca(H_2PO_4)_2$. Carbon dioxide solution was used as an extractant. Lower amounts were recovered when the H_3PO_4 was used.

It was believed by Dean (11) that phosphorus added to acid soils tends to accumulate in the alkali-soluble (adsorbed) forms, while phosphorus added to neutral or calcareous soils tends to accumulate in acid-soluble but alkali-insoluble forms.

Ammonium fluoride in neutral and acid solutions provided a means of fractionating the soil phosphorus as outlined by Bray and Dickman (6). Various fluoride extraction methods for phosphate were applied to a large number of soils in an attempt to measure the amount of adsorbed phosphates separately from the acid-soluble forms. They found that the addition of soluble phosphates to the soil increased only the adsorbed fractions. Rock phosphate increased the acid-soluble phosphate, but any conversion to adsorbed forms was found to occur only in acid soils, pH 4.8 to 5.0. Soils above pH 5.7 gave no increase in the adsorbed forms with rock phosphate additions. Increasing the amount of adsorbed forms by addition of soluble phosphates rapidly increased the usage of these forms by plants. Increasing the magnitude of the acid-soluble fraction produced no significant increases in crop growth.

Kurtz, DeTurk and Bray (20) found that nearly all of the phosphate added to samples of Illinois soils which was not recoverable in a water extraction was found in the adsorbed fraction. Conversion of the added phosphate into acid-soluble (.002 N sulfuric acid) proceeded slowly. In parts per million this conversion was not great, but it made up from 50 per cent of the total amount where additions were small to 5 per cent where additions were large. Believing that the phosphate extracted by the acid and 1 N ammonium fluoride could be utilized by plants they point out that the high recovery of the added phosphorus shows that little of the phosphate could be considered "fixed" in a sense that it would not be recoverable by plants.

Results with both oats and cotton indicated to Coleman (9) that these plants can utilize large amounts of adsorbed phosphate that could not be removed by Truog's dilute acid. This method did not remove all of the phosphate that was available to those crops.

Dean and Rubins (13), and Bray and Kurtz (7) arrived at much the same conclusions concerning the effect of pH on the acid-soluble and adsorbed phosphorus. The former state that in acid soils most of the applied phosphorus occurs as exchangeable phosphorus whereas in slightly alkaline soils containing a small amount of calcium carbonate the phosphorus occurs mostly as salts of divalent bases. The transition zone was found to be in the neighborhood of pH 6. The latter workers found that in untreated soils below a pH of 6.0 the adsorbed forms are relatively more abundant than at higher pH values. Added soluble phosphates change into these forms, whereas acid-soluble fractions are finally gradually dissolved and also increase the adsorbed forms. Above pH 6 the trend was the opposite.

Organic Phosphorus

Pierre and Parker (23), experimenting on the availability of organic phosphorus to plants, found that the organic phosphorus concentration was five times that of the inorganic phosphorus in the displaced soil solutions of 20 soils. Plants would not absorb organic phosphorus from soil extracts of the displaced solution while in the same experiment plants absorbed all the inorganic phosphorus. They point out, however, that organic phosphates may be made available to plants by biological agencies within the soil. The rapidity with which this takes place is believed to be due largely to the nature of the organic matter.

Rogers et al. (24) grew corn and tomato plants in the water extracts and displaced soil solution of Webster silt loam. The water soluble organic phosphorus was neither decomposed by the root enzymes nor absorbed by the plants to a measurable extent. These results are in agreement with those of Pierre and Parker.

In a survey of organic phosphorus content of western Oregon soils Bertramson and Stephenson (1) found that in older soils the phosphorus tends to accumulate in the form of rather stable organic compounds. They believed that these old soils have become biologically inactive and the old resistant residue of humus no longer decomposes readily or liberates appreciable quantities of phosphorus even though some of them were high in organic matter and organic phosphorus.

This concept is in agreement with the findings of Dyer and Wrenshall (16,17). They state that many soils having a high concentration of organic phosphorus are very deficient in available phosphorus, and that infertile, acid soils usually contain a high proportion of this fraction.

In England, Dean (12) observed large amounts of organic phosphorus with a close relation to the carbon content of soils.

Among dark-colored Iowa soils it was found by Pearson and Simonson (22) that the Edina series (planosol) and the Carrington series (Iowan drift) contained a greater per centage of organic phosphorus than did the Marshall, which is formed on loess of a much more recent age. The two older soils are acid in reaction, while the Marshall is approximately neutral.

From results with soil fungi Chang (8) concluded that as long as the phosphorus requirements of organisms exceed the amount derived by the organisms from organic compounds synthesis exceeds mineralization. When these organic phosphorus compounds provide more phosphorus than is required for synthesis the excess is liberated as inorganic phosphorus.

Bray and Kurtz (7) sum up the importance of organic phosphorus thus: "The organic forms of phosphorus are of importance in fertility because they are, in general, an indirect source of the soluble forms. Phosphates, as well as nitrates, are produced when soil organic matter is decomposed. After liberation, soil reactions sooner or later make the phosphates a part of the adsorbed and acid-soluble forms. Thus, they help counterbalance the effect of crop removal, and in highly organic soils a good level of the available forms is often maintained over a period of years despite crop removals. But it is the level of the available forms already present, not the amount liberated from the organic matter during the growing season, which appears to determine the fertility of the soil for that season as far as phosphorus is concerned."

PLAN OF STUDY

In order to evaluate the correlations between crop response to added phosphate and the quantities of acid-soluble, adsorbed and organic phosphorus in Michigan soils a number of soils were analyzed for these fractions according to the procedures developed by Bray and Kurtz (7). Samples for this study were obtained as follows:

In the spring of 1946 the Soil Science Department laid out six 12' x 36' field plots at 105 locations in the lower peninsula of Michigan for the purpose of studying correlations between crop response and rapid soil tests for potassium, phosphorus and magnesium. Plots were established as shown below, in fields where legume hay or small grain was grown.

B	P_2O_5	E	P_2O_5-K_2O - B
A	Check	D	P_2O_5-K_2O
C	K_2O	F	P_2O_5-K_2O - Mg

For the laboratory determinations, 38 locations, representing 18 soil series, which showed high or low crop response to added phosphorus were selected as follows:

Alfalfa: 13 soils showing high response
12 soils showing low response

Wheat and oats: 7 soils showing high response
6 soils showing low response

Before fertilizer was broadcast, 18 auger borings to a six-inch depth were taken from each plot at each location. Soils from the C plots (potash) and D plots (phosphorus and potash) were used in the analytical determinations. (See Fig. 1 for locations.)

For the purpose of establishing possible relationships between the fractions of the soil phosphorus and other soil properties, pH, particle size distribution and organic matter content were also determined for each location.

In order to test the reliability of the field plot yield data and to observe the effects of phosphorus applications under controlled conditions soils from ten of the locations where alfalfa was grown were studied in a greenhouse experiment. These included five low-responding, and five high-responding soils. Samples were composited from sites adjacent to the perimeter of the plots near, or after the close of the growing season. It was believed that samples so collected would have a nutrient content and other properties quite similar to the soils in the plots before fertilizer was applied.

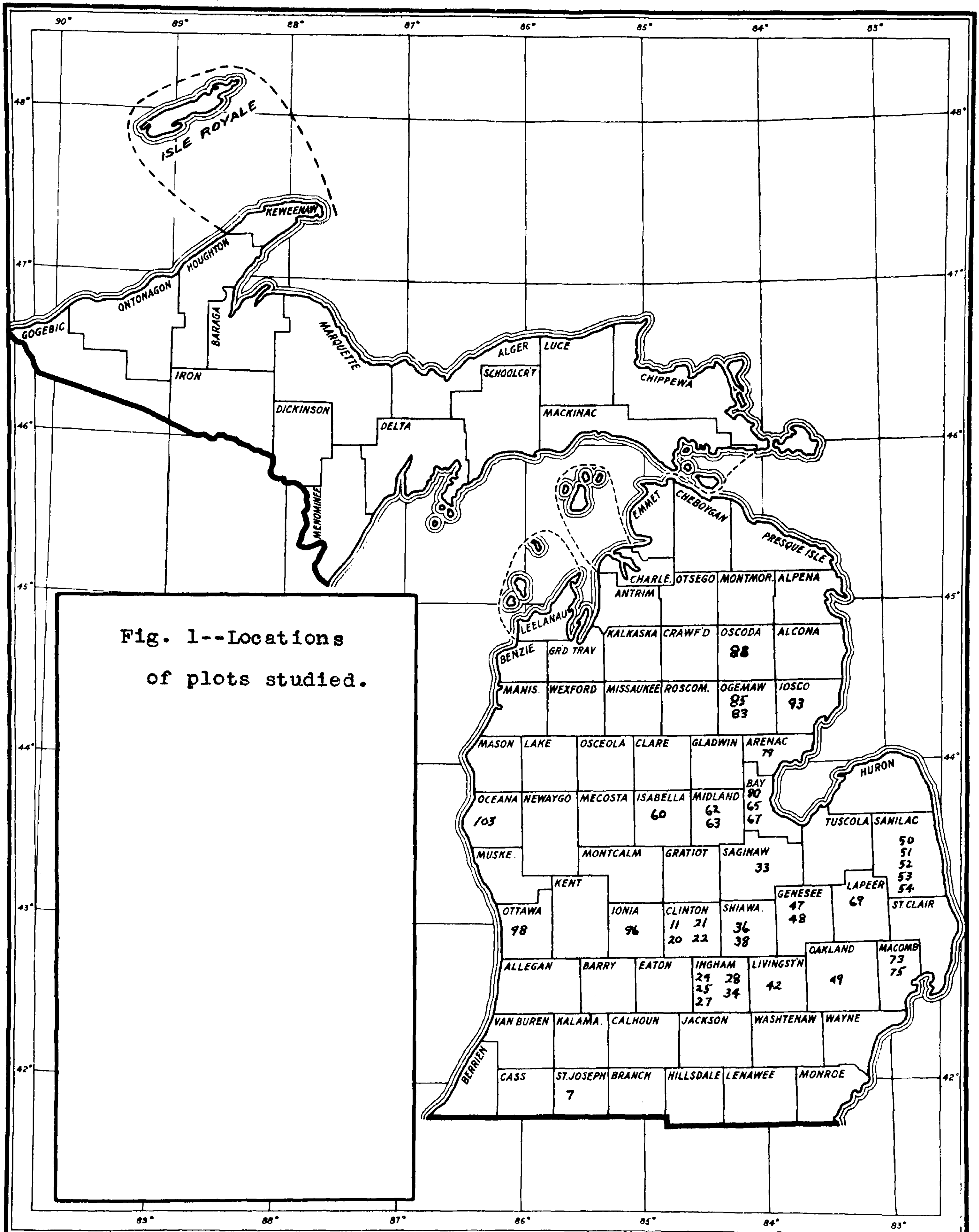


Fig. 1--Locations of plots studied.

EXPERIMENTAL PROCEDURE

Laboratory Determinations

Preparation of Soil Samples: At time of sampling, soils had been dried and passed through a 2 mm. sieve. Preliminary trials of the analytical procedures showed that for accurate results finer samples were required. All samples were therefore passed through a 35-mesh sieve. Duplicate 1-gram samples from the C and D plots of each location were used for the determinations. Possible differences between phosphorus levels of the plots receiving no phosphorus and those on which applications were made could thereby be allowed for in correlating responses.

The following reagents were used in making the determinations:

Ammonium molybdate-hydrochloric acid: Dissolve 15 gm. of reagent grade ammonium molybdate in about 350 ml. of distilled water. Add 350 ml. 10 N hydrochloric acid with stirring. Cool to room temperature and dilute to 1000 ml. with water.

Stannous chloride: Stock solution is made by dissolving 10 gm. of reagent grade stannous chloride dihydrate in 25 ml. concentrated hydrochloric acid. The solution is kept in a dark bottle and should be prepared fresh every two months. Dilute reagent is made up by adding 1 ml. of the stock solution to 1/3 liter of water.

Approximately 0.5 N ammonium fluoride: 18.5 gm. solid ammonium fluoride is dissolved in 1 liter of water and adjusted to pH 7.

Approximately 0.8 M boric acid solution: 50 gm. reagent grade boric acid is dissolved in 1 liter of warm distilled water.

0.1 N hydrochloric acid: 8.1 ml. concentrated hydrochloric acid is diluted to 1000 ml. with water.

Solid ammonium fluoride

0.5 N hydrochloric acid

Phosphorus-free hydrogen peroxide: 30% strength technical grade hydrogen peroxide is distilled under reduced pressure at a temperature not exceeding 60°C.

Total Adsorbed Phosphorus: One gram of NH_4-saturated soil was placed in a 125 ml. Erlenmeyer flask together with 50 ml. 0.5 N ammonium fluoride and shaken for one hour in an end-over-end shaker. After filtering the suspension in a glass or Buchner funnel a 10 ml. aliquot of the clear filtrate was transferred with a pipette into a 50 ml. graduate cylinder. 15 ml. of 0.8 M boric acid was added and the volume was brought to exactly 35 ml. with water. Ten ml. of ammonium molybdate-hydrochloric acid reagent was pipetted into the solution and mixed, followed immediately by 5 ml. of dilute stannous chloride solution. After mixing again and allowing 5 minutes for color to develop phosphorus concentration was determined in an Evelyn photoelectric colorimeter equipped with a 620 mu filter.

Total Acid-soluble and Adsorbed Phosphorus: One gram of air-dried soil was shaken with 50 ml. 0.1 N hydrochloric acid for 30 minutes. One gram of solid ammonium fluoride was then added, making the solution approximately 0.5 N in fluoride and the shaking was continued for one hour. After filtering the suspension and taking a 10 ml. aliquot the procedure outlined before for Adsorbed Phosphorus was followed. After determining phosphorus concentration in the colorimeter the Total Acid-Soluble Phosphorus was calculated by difference.

Organic Phosphorus: One gram of air-dried soil was weighed into a large test tube graduated at 50 ml. Phosphorus-free hydrogen peroxide, equivalent to approximately 15 ml. of 30 per cent strength and 10 ml. water were added and mixed thoroughly. The tube was then placed in a hot water bath for one hour. 15 ml. water, 10 ml. 0.5 N hydrochloric acid were added and the mixture was finally made up to 50 ml. with water. After shaking 30 minutes, one gram of ammonium fluoride was added and the suspension shaken for an additional hour. Following filtration, a 10 ml. aliquot was placed in a 250 ml. beaker, 15 ml. 0.8 M boric acid was added, and the mixture was evaporated to dryness on a hot plate. Ten ml. 0.1 N hydrochloric acid was placed in the beaker and the mixture was again evaporated. Residue was taken up with small portions of 0.1 N hydrochloric acid, transferred to a 50 ml. graduate cylinder, and phosphorus was determined according to the procedure described above for acid-soluble and adsorbed phosphates.

The organic phosphorus is taken as the difference between the phosphorus removed by this procedure and that removed from duplicate samples in the acid-soluble and adsorbed phosphate determination.

Organic matter content was determined by the wet combustion method of Walkley and Black (29).

The Hydrometer method of Bouyoucos (3) was used in making the mechanical analyses.

Hydrogen ion concentration was determined with the glass electrode.

Data on the above soil properties is given in Tables 5 and 6.

Greenhouse Experiment:

Soils from the 10 locations were sieved through a ½-inch screen. The experiment was set up to provide fertilizer treatments similar to those received by the field plots. Since the feeding area of the roots was limited, fertilizer applications were double those applied to the field plots. Fertilizer salts were thoroughly mixed with the soils in 2-gallon glazed pots with each treatment set up in triplicate as follows:

A. Check. 50 lb. nitrogen per acre as ammonium sulfate to start seedlings.

B. 300 lb. P_2O_5 per acre as mono-calcium phosphate plus 50 lb. nitrogen as ammonium sulfate.

C. 300 lb. K_2O per acre as potassium chloride plus 50 lb. nitrogen as ammonium sulfate.

D. 300 lb. P_2O_5 per acre as mono-calcium phosphate plus 300 lb. K_2O as potassium chloride with 50 lb. nitrogen per acre as ammonium sulfate.

After mixing, the soil was moistened in excess of moisture equivalent and maintained thus for one week previous to seeding. Alfalfa (Hardigan variety) was seeded in the pots on February 15th. The soils were maintained at close to their moisture equivalent (as determined by the suction method of Bouyoucos (2)) until six weeks after seeding after which time water was added as required. First cutting was made May 4th and the second cutting June 10th.

DISCUSSION OF RESULTS

Analytical Determinations:

Soils were designated "high-responding" or "low-responding" according to whether increase in yield of alfalfa or small grain was above or below the mean increase for the respective crops. Mean yields, the amounts of total adsorbed, acid-soluble, total adsorbed plus acid-soluble, and organic phosphorus, together with the sum of the three fractions is given in Tables 1-4. This data is presented graphically in Figs. 2 and 3.

Soils on Which Alfalfa was Grown: The total adsorbed fraction ranged from 21 to 90 ppm., with an average of 41 ppm. on the low-responding soils. On soils showing high response the range was from 11 to 35 ppm. and averaged only 22 ppm., or 19 ppm. less than the low-responding soils.

Acid-soluble phosphorus ranged from 57 to 126 ppm., averaging 78 ppm., in the low-responding soils, and from 15 to 101 ppm. with an average of 49 ppm. in the high-responding soils. It is of interest to note that while the soil (#52) with 101 ppm. acid-soluble phosphorus was highest for this fraction it was extremely low (13 ppm.) in the adsorbed fraction and showed a significant response to added phosphorus.

Contents of the total adsorbed plus acid-soluble phosphorus varied in the low-responding soils from 81 to 182 ppm., averaging 119 ppm., while in soils of high response the variation was between 29 and 116 ppm. with a mean of only 71 ppm.

With organic phosphorus the trend was reversed. In the

Table 1. Phosphorus contents of soils showing <u>less</u> than mean increase in alfalfa yield with added phosphorus

Plot No.	Soil Type	Inc. in yield	Total Adsorbed	Acid Soluble	Total Adsorbed + Acid Soluble	Organic	Total Ads. + Acid Sol. + Organic
		T/A	ppm.	ppm.	ppm.	ppm.	ppm.
11	Miami loam	.08	30.0	65.0	95.0	49.2	144.2
20	Bellefontaine sandy loam	.47	60.0	122.2	182.2	145.0	327.2
21	Miami loam	.19	21.2	60.0	81.2	96.0	177.2
22	Conover loam	.31	17.5	77.5	95.0	48.7	142.7
28	Miami loam	.07	45.0	125.7	170.7	121.5	292.2
*36	Miami clay loam	-.51	32.5	56.2	88.7	46.2	134.9
*42	Coloma loamy sand	-.20	90.0	76.2	166.2	0.0	166.2
62	Kawkawlin sandy loam	0.00	16.2	75.0	91.2	135.0	226.2
*65	Kawkawlin sandy loam	-.37	45.0	80.0	125.0	74.0	199.0
*80	Nester loam	-.03	38.7	73.7	112.4	55.0	167.4
*85	Nester sandy loam	-.04	31.2	72.5	103.7	65.0	168.7
*103	Isabella sandy loam	-.07	65.0	57.5	122.5	40.0	162.5
	Average		41.2	78.1	119.0	71.3	189.0

*Fertilized in 1944 or 1945
Mean increase in alfalfa yield = .76 tons per acre.

Table 2. Phosphorus contents of soils showing <u>greater</u> than mean increase in alfalfa yield with added phosphorus.

Plot No.	Soil Type	Inc. in yield	Total Adsorbed	Acid Soluble	Total Adsorbed + Acid Soluble	Organic	Total Ads. + Acid Sol. + Organic
		T/A	ppm.	ppm.	ppm.	ppm.	ppm.
24	Conover loam	0.88	23.7	73.7	97.4	37.5	134.9
*25	Conover loam	1.03	26.2	66.2	92.0	17.5	109.5
33	Oshtemo loamy sand	0.98	35.0	81.2	116.2	81.2	197.4
38	Brookston sandy clay loam	1.04	20.0	43.7	63.7	181.2	244.9
50	Napanee clay loam	1.59	11.2	18.7	29.9	55.0	84.9
52	Miami sandy clay loam	1.42	13.7	101.2	114.9	39.5	151.9
54	Napanee clay loam	2.15	17.5	38.7	56.2	126.2	182.4
63	Ogemaw sandy loam	1.36	23.7	82.5	106.2	232.5	338.7
69	Miami clay loam	1.05	10.0	21.2	31.2	47.5	78.7
*73	Brookston sandy clay loam	1.68	31.2	32.5	63.7	337.2	401.0
*75	Napanee sandy clay loam	1.18	25.0	15.0	40.0	145.0	185.0
*93	Selkirk loam	3.09	21.0	47.0	68.0	81.2	149.2
*96	Conover loam	1.56	32.5	21.2	53.7	146.0	199.7
	Average		22.0	49.1	71.3	117.2	188.4

*Fertilized in 1944 or 1945

Mean increase in alfalfa yield = .76 tons per acre

Table 3. Phosphorus contents of soils showing <u>less</u> than mean increase in yield of small grain with added phosphorus.

Plot No.	Soil Type	Inc. in yield	Total Adsorbed	Acid Soluble	Total Adsorbed + Acid Soluble	Organic	Total Ads. + Acid Sol. + Organic
		Bu/A	ppm.	ppm.	ppm.	ppm.	ppm.
/ 7	Fox loam	-7.5	50.0	118.7	168.7	8.7	177.4
*/34	Brady sandy loam	-2.7	20.0	56.2	76.2	70.0	146.2
*47	Gilford loamy sand	-3.2	61.2	123.5	184.7	181.2	365.9
*48	Fox loamy sand	-1.3	45.0	102.5	147.5	131.7	279.2
51	Miami loam	-15.2	27.5	72.5	100.0	80.0	180.0
*53	Napanee loam	-16.4	35.0	53.7	88.7	143.7	232.4
	Average		39.7	87.7	127.6	102.5	230.0

/ Wheat
* Fertilized in 1944 or 1945
Mean increase in oat yield = 9.3 bu. per acre.

Table 4. Phosphorus contents of soils showing <u>greater</u> than mean increase in yield of small grains with added phosphorus.

Plot No.	Soil Type	Inc. in yield	Total Adsorbed	Acid Soluble	Total Adsorbed + Acid Soluble	Organic	Total Ads + Acid Sol. + Organic
		Bu/A	ppm.	ppm.	ppm.	ppm.	ppm.
/27	Coloma sand	14.1	78.7	112.2	190.9	0.0	190.9
49	Fox sandy loam	11.1	38.7	110.0	148.7	72.5	221.2
*60	Isabella sandy loam	15.1	62.5	58.7	121.2	78.7	199.9
*79	Arenac loamy sand	47.9	26.2	38.6	64.9	36.2	101.1
*83	Nester loam	17.5	47.5	67.5	115.0	51.2	166.2
88	Emmett sandy loam	10.0	41.2	101.2	142.5	15.0	157.5
*98	Berrien loamy sand	16.2	32.5	40.0	72.5	118.2	190.7
	Average		46.7	75.4	122.0	53.0	175.3

/ Wheat
* Fertilized in 1944 or 1945
Mean increase in oat yield = 9.3 bu. per acre.

low-responding soils there was a range from 0 to 145 ppm. with a mean of 71 ppm. The high-responding soils, however, had an extreme range from 17 to 337 ppm. and a mean of 117 ppm. Three soils with a large organic phosphorus content were responsible for the high average.

Where amounts of total adsorbed plus acid-soluble plus organic phosphorus were compared the range in low-responding soils was from 135 to 327 ppm.; that in the high-responding soils from 78 to 338 ppm., while the averages were nearly equal--189 ppm. in the former and 188 ppm. in the latter group.

Soils on Which Small Grain was Grown: Differences in the contents of the various fractions of the soil phosphorus were not so marked between high- and low-responding soils as they were on the alfalfa plots. In low-responding soils the total adsorbed phosphorus varied from 20 to 61 ppm., averaging 39 ppm., while on high-responding soils the range was from 26 to 78 ppm. and averaged 46 ppm.

Acid-soluble phosphorus ranged from 53 to 123 ppm., with an average of 87 ppm., in the low-responding soils. In the high-responding soils this fraction showed a range from 38 to 112 ppm., while averaging 75 ppm.

Soils showing low response indicated a variation of from 76 to 184 ppm. total adsorbed phosphorus plus acid-soluble phosphorus while averaging 127 ppm. High-responding soils were but little different, with a range from 65 to 190 ppm. and an average content of 122 ppm.

The trend in organic phosphorus was opposite to that found in the soils on which alfalfa was grown. Those soils showing the greatest increases in yield contained the highest average amount of organic phosphorus. Such was not the case with small grain. In soils showing low response the range was from 8 to 181 ppm. with an average of 102 ppm., but in high-responding soils with a range from 0 to 78 ppm. the average was only 53 ppm.

These differences in organic phosphorus caused the sum of the fractions in the low-responding soils to vary from 146 to 365 ppm. and to average 230 ppm. while the high-responding soils showed a range from 101 to 221 ppm. and an average of 175 ppm.

Corrèlation with Crop Response:

Alfalfa: The relationship between the response of alfalfa to added phosphate and the contents of the subject fractions of soil phosphorus or combinations thereof are shown in Figs. 4, 5, 6, 7, and 8. Correlation coefficients were determined and significance established according to Fisher's Tables. For the number of determinations in this study a correlation coefficient of -.40 was necessary for a relationship to be of significnae.

The relation between the total adsorbed phosphorus and response of alfalfa to added phosphorus produced a correlation coefficient of -.47, which is barely significant (Fig. 4). With the acid-soluble fraction there was no significant relationship (ryx = -.41) (Fig. 5). This low correlation may

Fig. 2—Comparison of phosphorus levels between soils showing high response and soils showing low response to added phosphate on alfalfa.

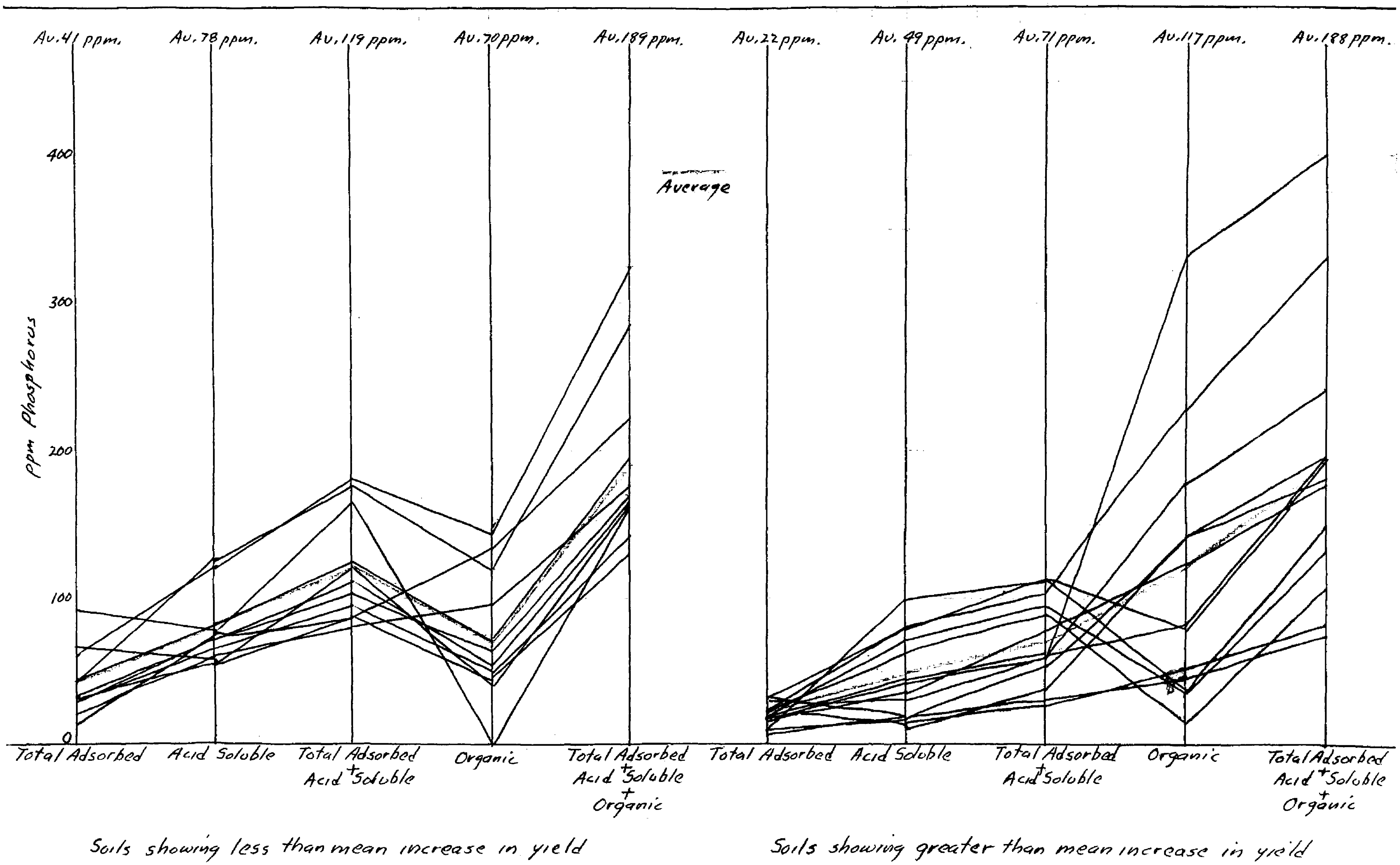
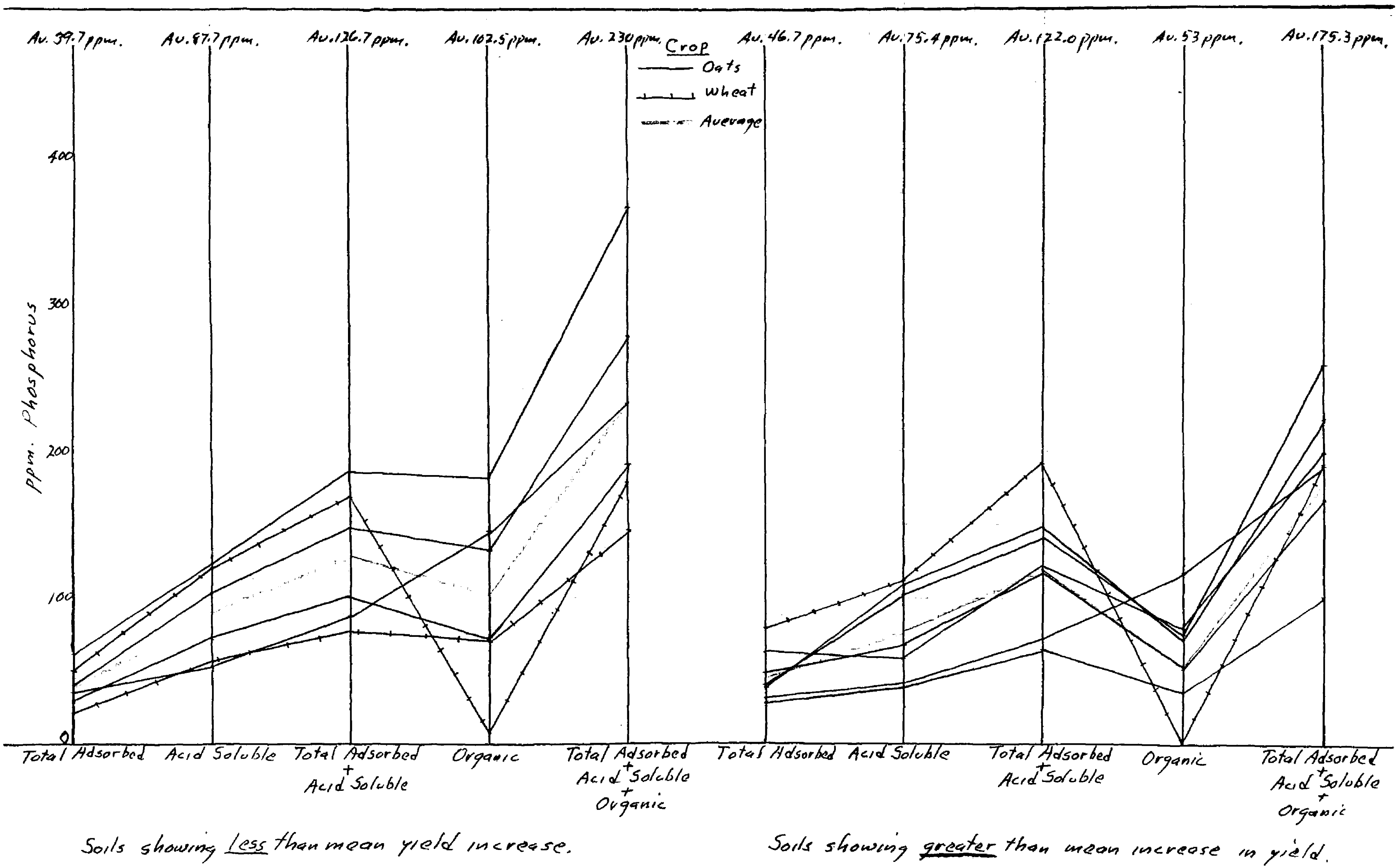


Fig. 3—Comparison of phosphorus levels between soils showing high response and soils showing low response to added phosphate on oats.



be explained through reference to Fig. 2. There it will be seen that five of the soils with greater than mean yield increase had an acid-soluble phosphorus content of more than 50 ppm., or equal to the acid-soluble phosphorus content of eight of the soils showing less than mean increase in yield.

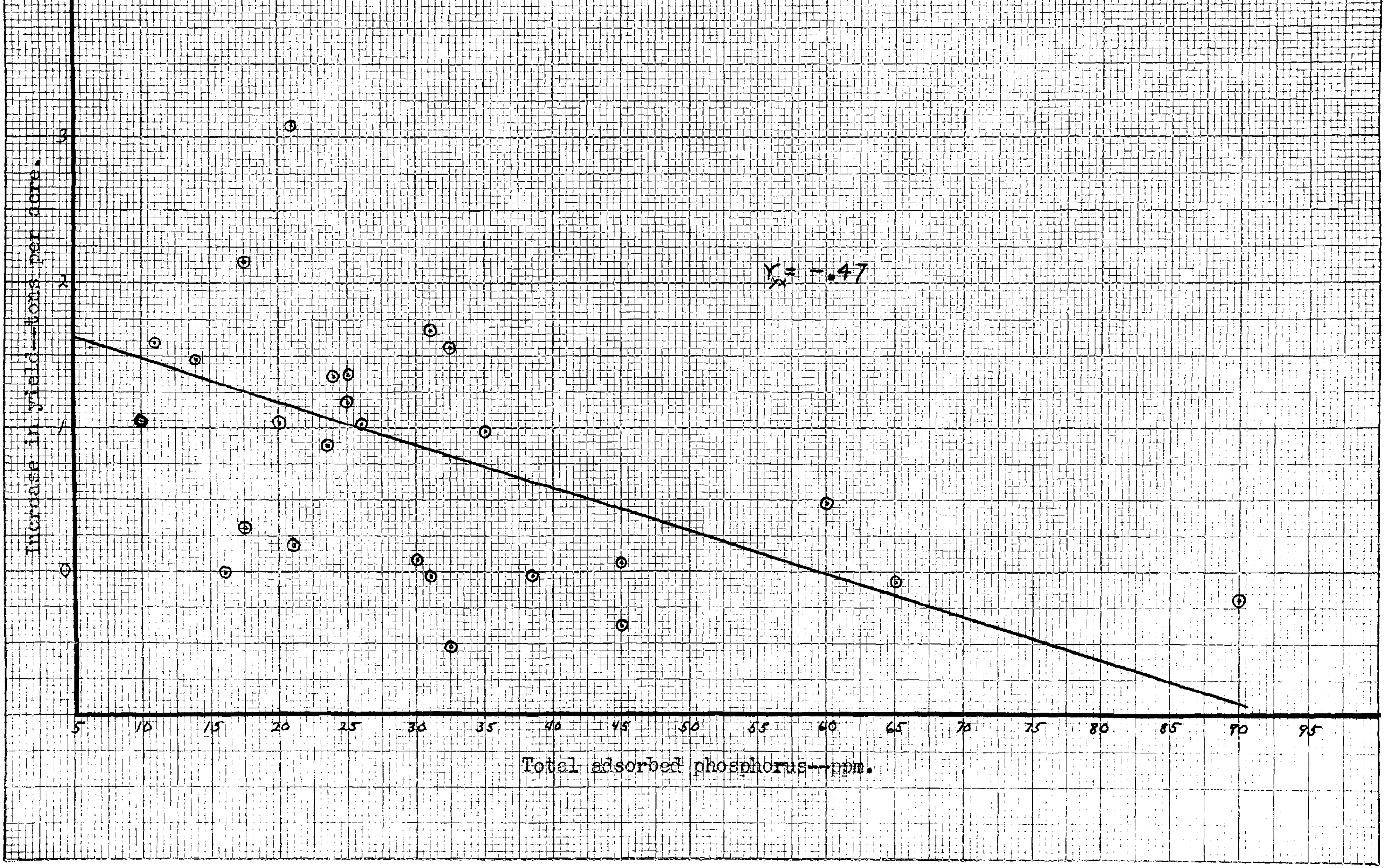
Of the five soil phosphorus fractions or combinations of fractions, the adsorbed plus acid-soluble gave the most significant correlation ($r_{yx} = -.54$) Fig. 6). This is in harmony with the observations of Bray and Dickman (6), who pointed out that crop growth and response for the soils and crops of Illinois are generally correlated with the relative amounts of all fractions present, not with the amount of any one fraction. Bray* has also stated that the rapid test which removes a portion of both fractions gives a better correlation with crop response than laboratory methods specific for the total amount of each form.

There was apparently no relationship whatsoever between the organic phosphorus and response of alfalfa (Fig. 7). In this case the correlation coefficient was +.33. This value, if taken literally, would indicate that alfalfa responded more to added phosphate on soils of high organic phosphorus content than on soils low in this fraction. This is, of course, an impossible situation, but it does serve to point out that the organic phosphorus is totally unavailable to alfalfa.

The correlation coefficient of -.02, calculated for the relation between the sum of the fractions and yield increase

*Private communication.

Fig. 4.--Relation between response of alfalfa to added phosphate and the total adsorbed phosphorus in soils.



A. S.

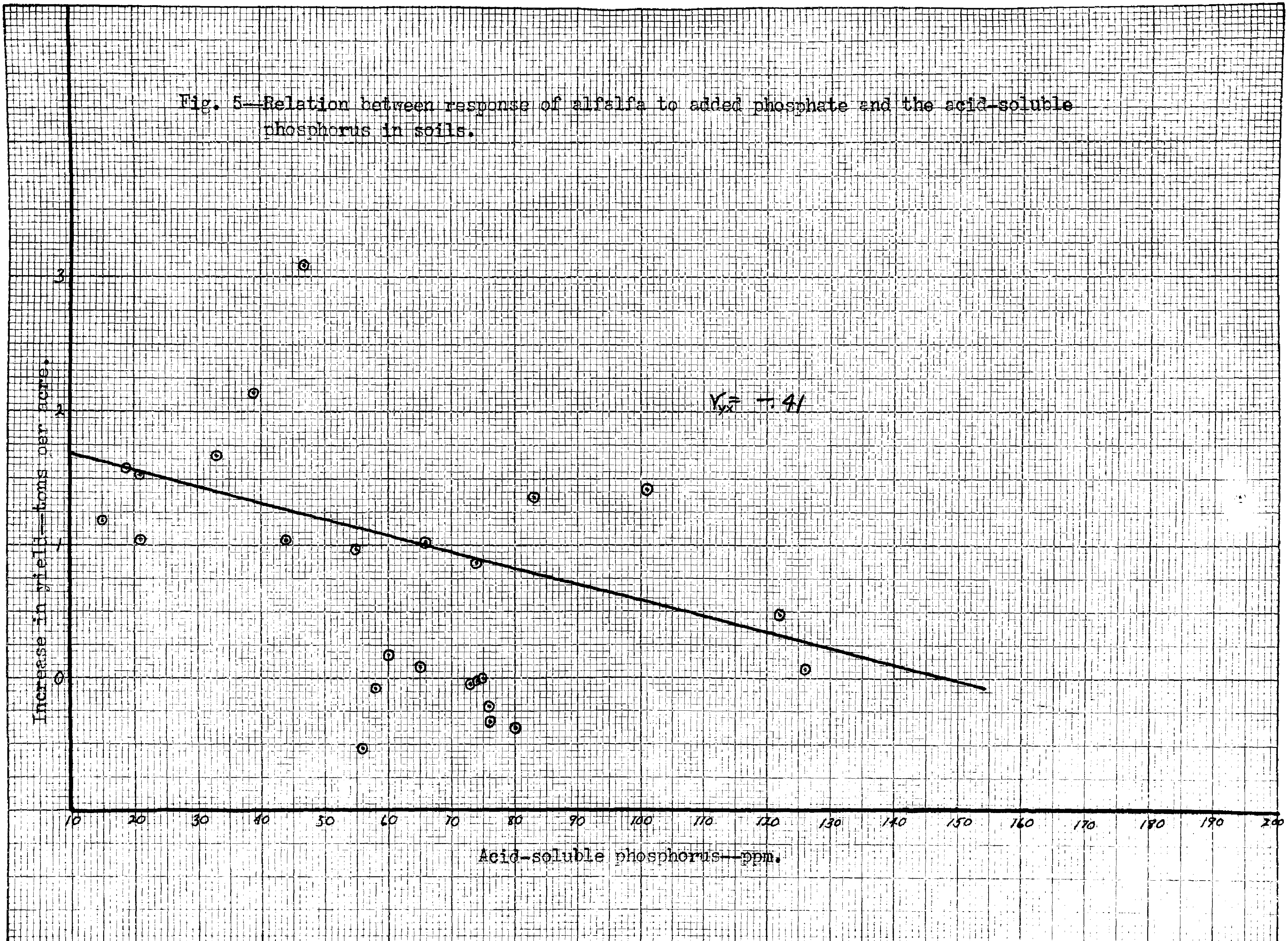


Fig. 5—Relation between response of alfalfa to added phosphate and the acid-soluble phosphorus in soils.

TA + AS

Fig. 6—Relation between response of alfalfa to added phosphate and the total adsorbed and acid-soluble phosphorus in soils.

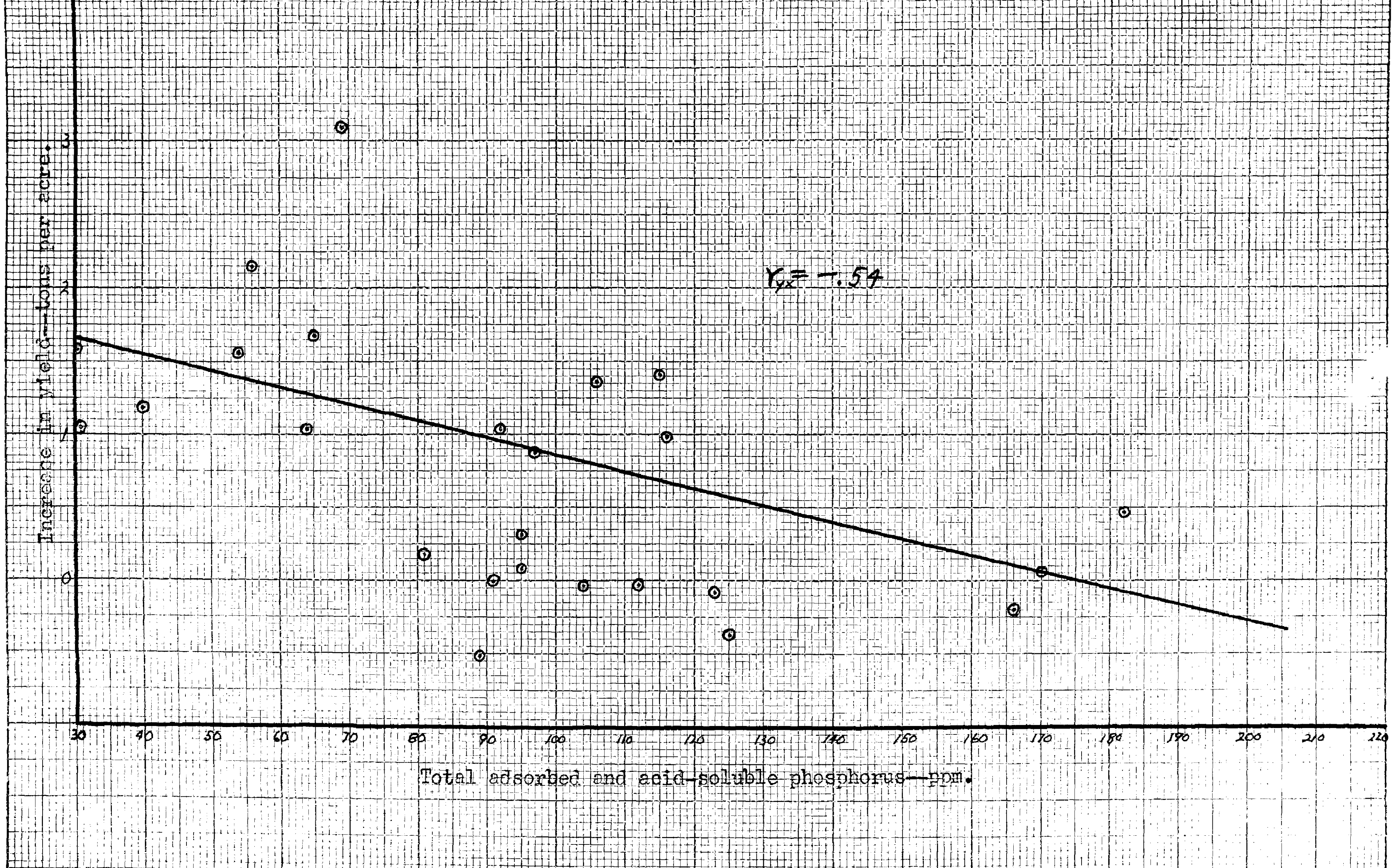


Fig. 7--Relation between response of alfalfa to added phosphate and the organic phosphorus in soils.

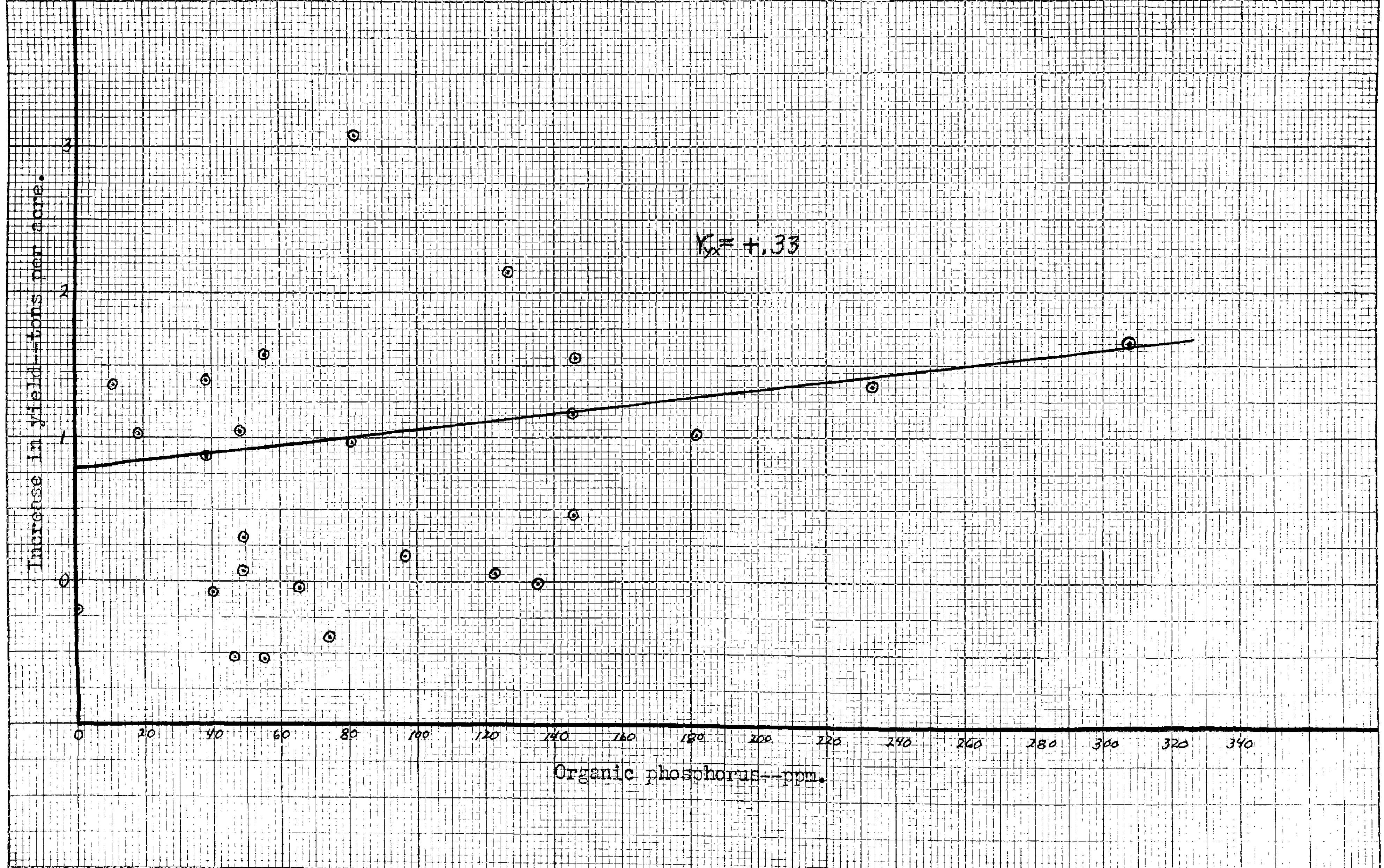
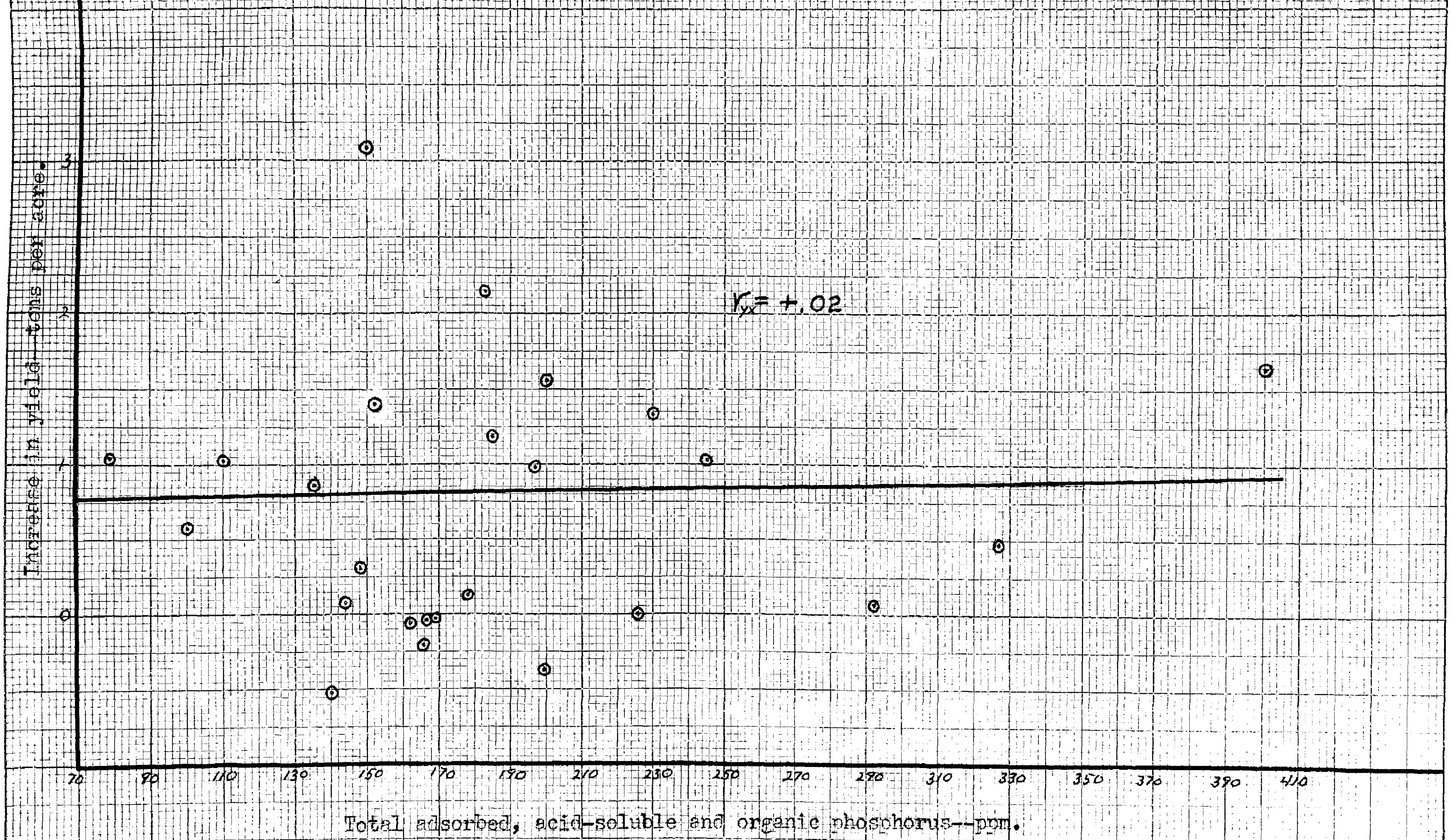


Fig. 8—Relation between response of alfalfa to added phosphate and the total adsorbed, acid-soluble and organic phosphorus in soils.



of alfalfa (Fig. 8) emphasized the futility of attempting to link the organic phosphorus in any way with crop response in a siggle season. It will be observed here that the significant correlation found with the adsorbed plus acid-soluble fractions (ryx = -.54) is completely nullified when correlation is attempted between those fractions plus organic phosphorus and response of alfalfa (ryx = -.02).

Oats: Since analytical data was available only for nine soils on which oats were grown, it was decided that with so limited a number of items statistical treatment was of no value. From a comparison of Tables 3 and 4, however, it will be seen that although the high- and low-responding soils contain similar average amounts of adsorbed and acid-soluble phosphorus there is a sharp difference between the average amounts of organic phosphorus present. The high-responding soils contained half as much of this fraction (53 ppm.) as the low-responding soils (102 ppm.). This relationship appears to be in direct opposition with correlations in alfalfa yield increases where the organic phosphorus had no effect on response. Since none of the high-responding soils are regarded as inherently fertile, while three of the four low-responding soils have a medium to high natural productivity, an explanation may be afforded by the observations of Wynd and Noggle (32).

They indicate that the growth of oats on some Kansas soils was more affected by the amount of replaceable bases in soils than by the content of adsorbed, acid-soluble or adsorbed plus acid-soluble phosphorus. Although no data on content of exchangeable bases in the subject soils was compiled, the fact that those showing the lowest phosphate response were of good fertility indicates a similar relationship. The average organic matter content was considerably above that of the high-responding soils, also. (Tables 5 and 6).

Relationships between Soil Phosphorus and Soil Properties:

Past Management: A study of fertilizer applications by farmers on all locations previous to establishment of the plots was made. There was no uniformity either as to the amounts or kinds of fertilizers used, but the over-all study revealed that soils to which phosphate had been added in 1944 or 1945 averaged 41 ppm. total adsorbed phosphorus, while unfertilized soils averaged only 27 ppm. No such relationship was evident with the acid-soluble fraction.. Fertilized soils averaged 72 ppm. to 67 ppm. in the unfertilized soils. Nine of the 22 high-responding soils and 11 of the 16 low-responding soils were fertilized in 1944 or 1945 (Tables 1-4). Since superphosphate rather than rock phosphate is the prevailing amendment in Michigan the observations of Bray and Dickman are born out (6). Under Illinois conditions they found that in acid soils added soluble phosphates rapidly change into the adsorbed forms, whereas acid-soluble portions are gradually dissolved and very slowly increase the adsorbed forms.

Influence of Soil Acidity: Of the soils above pH 6.8 it was found that 11 showed little or no response to added phosphate while only 2 showed a high response. Twenty-nine soils (Tables 5 and 6) were definitely acid in reaction

Table 5. Soil properties. Per cent organic matter, pH and per cent sand, silt and clay of soils showing <u>high</u> response to added phosphate.

Plot No.	Soil Type	Organic Matter	pH	Sand	Silt	Clay
		%		%	%	%
24	Conover loam	1.48	6.7	56	34	10
25	Conover loam	1.43	6.9	58	26	16
27	Coloma sand	0.85	6.7	87	9	4
33	Oshtemo loamy sand	3.84	6.6	80	10	10
38	Brookston sandy clay loam	2.08	6.6	60	22	12
49	Fox sandy loam	0.83	5.6	72	22	6
50	Miami clay loam	1.47	6.2	50	26	24
52	Miami sandy clay laam	1.43	6.6	64	24	12
54	Napanee clay loam	1.89	6.5	64	22	14
60	Isabella sandy loam	1.40	6.7	74	20	6
63	Ogemaw sandy loam	3.00	7.2	74	14	12
69	Miami clay loam	2.10	6.0	38	20	42
73	Brookston sandy clay loam	2.02	6.7	52	28	20
75	Napanee clay	1.79	5.9	50	12	38
79	Arenac sand	0.96	6.1	92	5	3
83	Nester loam	0.83	6.0	48	52	10
88	Emmett sandy loam	1.95	6.8	58	26	16
93	Selkirk loam	1.97	6.7	52	28	20
96	Conover loam	1.87	6.5	42	40	18
98	Berrien loamy sand	1.30	5.3	88	12	7

Table 6. Soil properties (cont'd.). Per cent organic matter, pH and per cent sand, silt and clay of soils showing <u>low</u> response to added phosphate.

Plot No.	Soil Type	Organic Matter	pH	Sand	Silt	Clay
		%		%	%	%
7	Fox loam	1.43	6.9	48	30	22
11	Miami clay loam	1.32	6.9	52	25	33
20	Bellefontaine sandy loam	0.83	6.8	70	18	12
21	Miami loam	1.82	5.3	48	28	24
22	Conover loam	1.56	6.6	58	26	16
28	Miami loam	1.74	7.8	58	24	18
34	Brady sandy loam	1.50	7.0	74	14	12
36	Miami clay loam	1.30	5.8	44	34	22
42	Coloma sand	0.54	6.1	89	7	4
47	Gilford loamy sand	2.02	7.3	82	11	7
48	Fox loamy sand	2.10	5.9	82	13	5
51	Miami sandy loam	1.43	6.0	76	18	6
53	Napanee clay loam	2.13	6.6	52	30	18
62	Kawkawlin loamy sand	1.74	7.3	82	12	6
65	Kawkawlin sandy loam	2.86	7.7	68	25	17
80	Nester loam	1.76	7.0	64	20	16
85	Nester sandy loam	1.82	6.7	78	12	10
103	Isabella sandy loam	1.27	6.9	75	20	5

(below pH 6.8). Six of these were low in their response while 23 gave significant increases in yield. This comparison is in accord with the recommendations of Scarseth (26) and numerous other workers, who show that maximum phosphate availability occurs just below neutrality.

The relation between pH and per cent total adsorbed phosphorus in the total adsorbed plus acid-soluble combination is shown in Fig. 9. There is a wide scattering of points and no trend is evident. Dean and Rubins (13) stated that the adsorbed fraction increased with acidity, especially below pH 6, while in slightly alkaline soils the acid-soluble fraction predominated. The transition zone, they believed, began in the neighborhood of pH 6. Since the majority of the soils studied fell into this transition zone between pH 6 and pH 7 the lack of definite relationship may be explained.

Influence of Organic Matter: As is shown in Fig. 10, the quantity of organic phosphorus generally increased with organic matter content. This might well be expected, but, as Dickman and DeTurk (14) point out, the amounts are not proportional. The organic matter contents of the majority of the soils studied varied in the narrow range between 1 and 2 per cent, as found by the wet combustion method, and within such limits a clean-cut trend in the relationship is difficult to follow.

Wynd and Noggle (31) found a positive relationship between organic matter content and adsorbed phosphorus in

Fig. 9--Relation between pH and per cent of total adsorbed phosphorus in the acid-soluble and total adsorbed fraction.

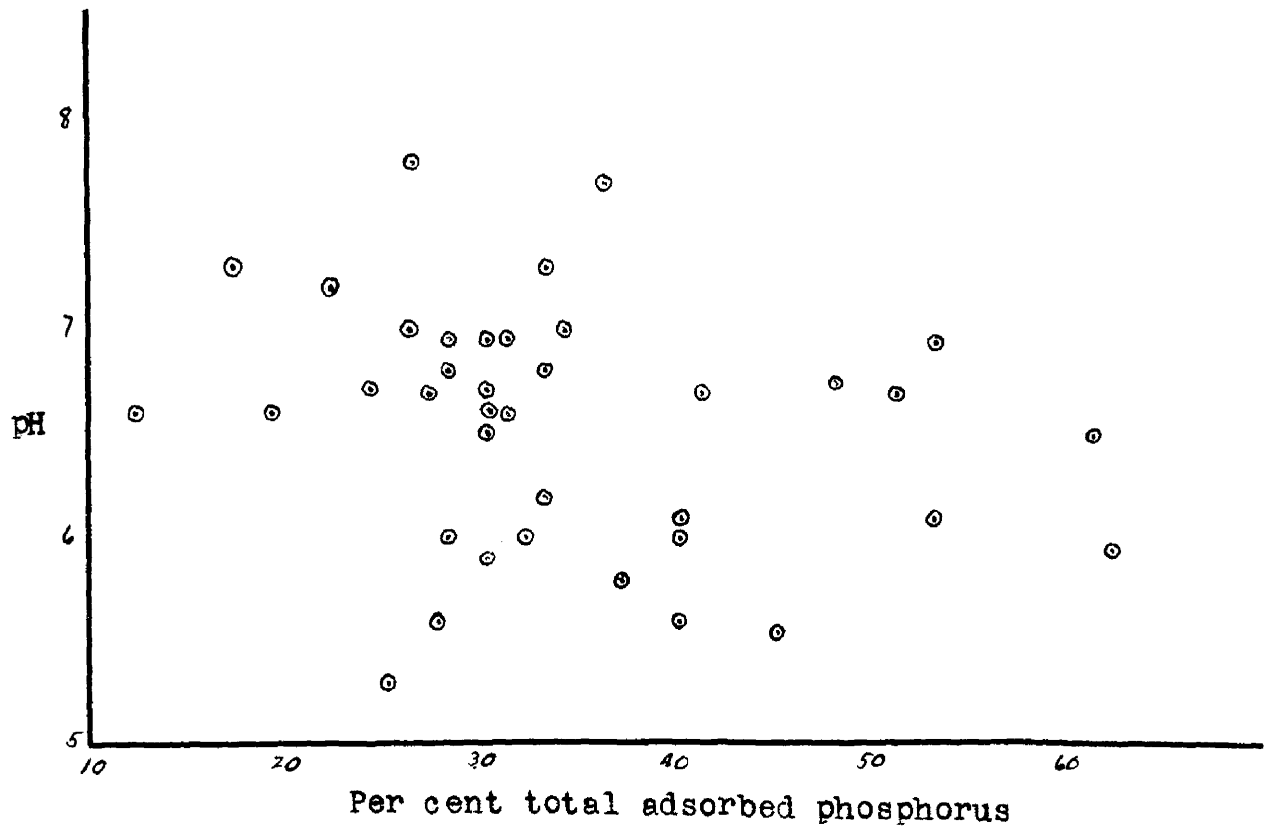


Fig. 10--Relation between organic matter and organic phosphorus content of soils.

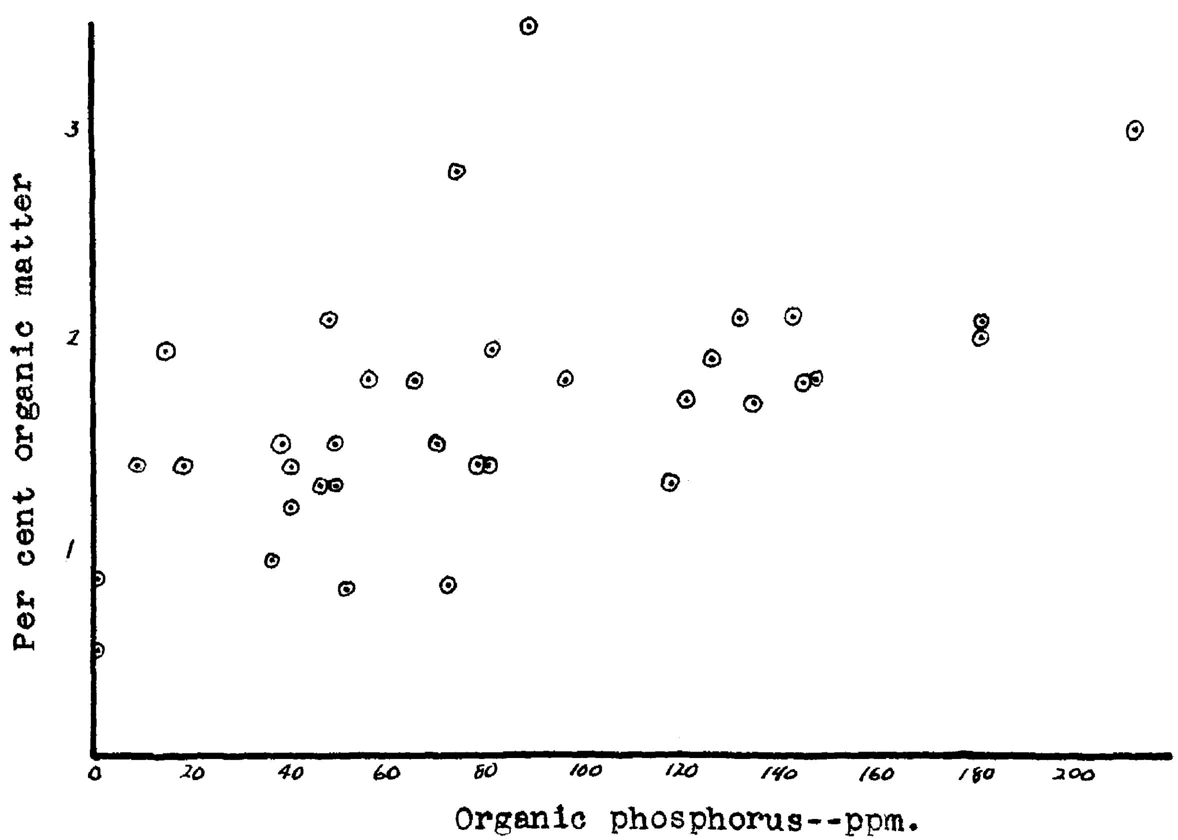
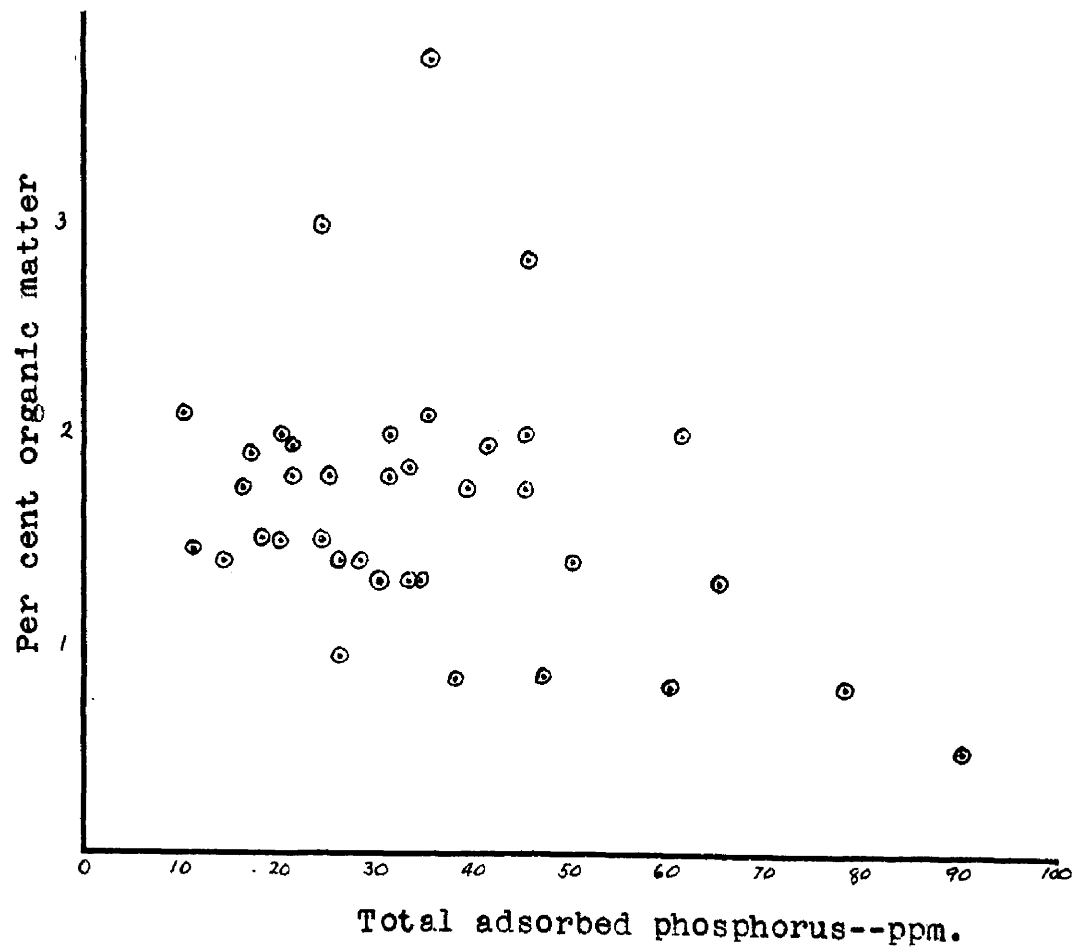


Fig. 11--Relation between organic matter and total adsorbed phosphorus of soils.



some soils of Kansas. This relationship is not evident in the soils studied, as is shown in Fig. 11. Again, the difference in results may be due to the low content and narrow range of organic matter in these soils. In Fig. 11 it will be noted that there is a large number of of soils containing between 1.25% and 2.25% prganic matter and that within this range the distribution of adsorbed phosphorus is scattered without noticeable trend within the limits of 10 and 45 ppm. In addition, the two soils highest in adsorbed phosphorus were among the lowest in organic matter content, while the three soils highest in organic matter were only medium in adsorbed phosphorus.

Influence of Particle Size Distribution: An inspection of Tables 5 and 6 reveals nothing to indicate relationship between per cent of sand, silt or clay with response or with content of any phosphorus fraction. In several instances representatives of the same soil series or soil type are found among the high-responding and also among the low-responding soils. From this study no generalizations can be drawn as to the behavior of a given soil series when phosphate is added, or to its phosphorus content. Past cropping history and soil management practices appear to be far more important than intrinsic characteristics of the soil itself in appraising its phosphorus fertility.

Greenhouse Results:

In the pot experiments duplicating field plot treatments on ten soils where alfalfa was grown, yields were comparable in result if not in magnitude with field results on the high-responding soils. (See Table 7 and Plates 4, 5, 7, 8 and 9). In some instances yields were higher, elsewhere lower, than the field results. In the greehhouse, crop responses were intensified by phosphate addition. As a result, soils from locations 11, 21 and 22, (Plates 1, 2 and 3) which gave low response in the field, produced marked response to phosphorus in the pot experiments. On the other hand, soils from locations 36 and 65, which were also low-responding, (Plates 6 and 10) showed quite comparable yields.

It is important to note that all three of the soils mentioned as having shown low response in the field and high response in the greenhouse were collected from locations in southern Clinton County (Fig. 1). In 1946 this area was subject to one of the worst droughts in the history of central Michigan, and it would appear that the lack of field response might have been due simply to a lack of sufficient moisture. Rainfall was apparently sufficient, however, to allow added potash salts to become soluble, for yield increases due to this amendment were marked in each of the three soils.

The data in Table 1 show that these three soils were not particularly high in the total adsorbed plus acid-soluble phosphorus among the low-responding soils, and when alfalfa was grown under conditions of plentiful moisture the deficiencies showed up. If we allow for the fact that soil taken from location 22 would have shown high response under favorable moisture conditions then the Conover series provides one exception to the previous statement--that no generalizations can be drawn as to the behavior of a given soil series to added phosphate. Including location 22, all four samples of Conover showed high response. If the greenhouse results are an indication of responses that might be expected in a growing season with sufficient moisture then the foregoing discussion provides an example of the need for several years' yield data in an investigation of this kind.

As might be expected, yields of the second cutting tended to level off between treatments although response indications were still definite. On the B treatment pots (phosphorus only) potash deficiency was noted in the second crop on soils 33, 38, 54, 25, 65 and 63. Leaf margins yellowed and the characteristic white dots appeared over the entire surfaces of the leaves. Of these, only soil 65 showed low response to phosphate in the field results, indicating a rather low general fertility level in these soils.

Table 7. Effect of added phosphorus on field plot and greenhouse yields of alfalfa. (First cutting).

Plot No.	Soil Type	Location	Treatment Check	P	K	PK
11	Miami clay loam	Field	3.82	3.92	4.05	4.13
		Greenhouse	1.78	2.23	1.35	1.91
21	Miami loam	Field	1.87	2.56	2.58	2.77
		Greenhouse	1.04	2.62	1.31	2.88
22	Conover loam	Field	1.71	2.61	2.70	3.01
		Greenhouse	1.39	3.01	1.70	3.44
25	Conover loam	Field	1.84	2.80	2.14	3.17
		Greenhouse	0.86	2.10	1.04	2.52
33	Oshtemo loamy sand	Field	1.52	2.66	1.56	2.54
		Greenhouse	1.17	2.53	1.57	2.53
36	Miami clay loam	Field	2.80	3.09	3.33	2.82
		Greenhouse	2.10	2.35	1.73	2.00
38	Brookston clay loam	Field	1.76	2.59	2.21	3.25
		Greenhouse	1.35	2.10	1.26	3.53
54	Napanee clay loam	Field	1.47	2.38	1.16	3.31
		Greenhouse	0.65	1.66	0.69	3.22
63	Ogemaw sandy loam	Field	1.26	1.97	1.63	2.99
		Greenhouse	1.78	2.23	1.61	2.53
65	Kawkawlin loamy sand	Field	2.91	3.09	3.28	2.91
		Greenhouse	3.35	3.40	3.87	3.25

SUMMARY AND CONCLUSIONS

In this investigation, involving greenhouse and laboratory studies, the objective was to determine the contents of adsorbed, acid-soluble and organic phosphorus in a number of soils showing high response and low response to added phosphate fertilizer. An attempt was made to correlate these fractions with response of alfalfa and small grain and to study the relationships between various soil properties and the forms of soil phosphorus.

In addition to the analyses for phosphorus, determinations for pH, organic matter and particle size distribution were conducted. In the greenhouse an experiment was set up to compare crop response under controlled conditions with responses observed in field plots.

As a result of these studies the following statements can be made:

1. With alfalfa, soils showing high response to added phosphate averaged considerably lower in adsorbed and in acid soluble phosphorus; much higher in organic phosphorus, and nearly the same in the sum of the three forms as soils showing low response.

2. The most significant negative correlation between increase in alfalfa yield and forms of soil phosphorus was found in the total adsorbed plus acid-soluble phosphorus.

3. There was absolutely no correlation between increase in alfalfa yield with added phosphate and the organic phosphorus content of soils. This lack of relationship was car-

ried over into the correlation between the sum of the three forms and alfalfa response.

4. Response in oats to phosphate apparently had the highest correlation with organic phosphorus content. Since this is in direct opposition to the findings with alfalfa it is possible that exchangeable base content, rather than phosphorus level, is responsible for the apparent anomaly.

5. A residual effect was observed from fertilizers applied previous to establishment of the plots. This carry-over was in the adsorbed fraction rather than the acid--soluble fraction.

6. It was indicated that maximum phosphate availability in the soils studied occurs just below the neutral point. The majority of soils above pH 6.8 showed little or no response to added phosphate while an equally large majority below pH 6.8 showed high response. There was a wide variation of phosphorus content in both series.

7. With increase in organic matter content organic phosphorus also increased, though not proportionally.

8. No relationship could be discerned between organic matter content and amount of adsorbed phosphorus. This may be due to the narrow range (1.25--2.25%) of organic matter in which the majority of the soils fell.

9. Particle size distribution is of no value in appraising phosphorus level or forms. Representatives of the same soil type were found in both high- and low-responding soils.

10. A greenhouse experiment produced yields which were comparable to field results on high-responding soils. Responses were intensified under controlled conditions and three soils which showed low response in the field produced substantial increases in the greenhouse.

11. In view of the above, it is believed that several years' yield data should be accumulated before a soil is finally adjudged high- or low in response to added phosphate. From the data reported herein no correlation of very high significance was found between the fractions of the soil phosphorus and crop response to added phosphate. The best correlation was found in the adsorbed plus acid-soluble phosphorus rather than in any single fraction determined. These results concur with findings of the originators of the analytical methods used.

Plates 1-10. The effect of added phosphorus on the growth of alfalfa on soils from 10 locations. See Table 7 for yield data. Photographs made 9 weeks after seeding.

Plate 1. Plot No. 11. Miami clay loam.

Plate 2. Plot No. 21. Miami loam.

Plate 3. Plot No. 22. Conover loam.

Plate 4. Plot No. 25. Conover loam.

Plate 5. Plot No. 33. Oshtemo loamy sand.

Plate 6. Plot No. 36. Miami clay loam.

Plate 7. Plot No. 38. Brookston clay loam.

Plate 8. Plot No. 54. Nappanee clay loam.

Plate 9. Plot No. 63. Ogemaw sandy loam.

Plate 10. Plot No. 65. Kawkawlin loamy sand.

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