A Test for Water-Soluble Phosphorous – Field Soils
Michigan State University Agricultural Experiment Station
Technical Bulletin
C.H. Spurway, Soils
Issued August 1929
25 pages

Oakly Lardie

Technical Bulletin No. 101 August, 1929

A TEST FOR WATER-SOLUBLE PHOSPHOROUS

Studies on Water-Soluble Phosphorous in Field Soils

By C. H. SPURWAY

AGRICULTURAL EXPERIMENT STATION
MICHIGAN STATE COLLEGE
Of Agriculture and Applied Science

SOILS SECTION

East Lansing, Michigan

TABLE OF CONTENTS

STUDIES ON WATER-SOLUBLE PHOSPHORUS IN FIELD SOILS

By C. H. SPURWAY

Introduction

The studies described in this bulletin were conducted for the purpose of gathering information on the solubility of the phosphorus contained in some commercial fertilizers when applied in different amounts to various soils under normal field conditions. In addition to the degree of solubility of phosphorus in soils, data are presented showing how water-soluble phosphorus is distributed in certain soils fertilized with phosphorus fertilizers, and showing also the effects of different methods of applying fertilizers on the distribution of water-soluble phosphorus within the soil.

By determining water-soluble phosphorus in soils growing potatoes, which were fertilized with different amounts of phosphorus, a relationship has been discovered between yield of potatoes and amount of water-soluble phosphorus found in the soils.

All of the data presented in this publication were obtained by means of a rapid test for water-soluble phosphorus in soils. This test is described as a separate part of the bulletin in order to present all of the data on these soil-phosphorus studies in one publication.

A TEST FOR WATER-SOLUBLE PHOSPHORUS

The determinations of water-soluble phosphorus in soils presented in this bulletin were made by means of a micro-chemical phosphorus test developed by the author and based on the reaction of Deniges. Deniges (1) showed that the chemical reaction between phosphorus in the form of orthophosphate and a solution of ammonium molybdate in the presence of nitric acid is extremely sensitive; and that the chemical reduction of the molybdenum in the ammonium phospho-molybdate compound thus formed, by means of stannous chloride, gives a blue color.

Silicon, acts similarly to phosphorus in this reaction, and as the testing for phosphorus in soil extracts must be done in the presence of water-soluble silica, if rapid testing is accomplished, the effects of silica on the reaction had to be eliminated. This is accomplished by carrying out the reduction process in a strong nitric acid solution and the ammonium molybdate reagent is prepared with nitric acid of suf-

1. An Extremely Sensitive Reaction of Phosphate and Arsenates and Its Application. G. Deniges. Compt. rend. 171, 802-4 (1920).

ficient strength so that when diluted with equal parts of soil extract, the resulting mixture contains the proper concentration of acid.

The technic of Deniges is also further modified by stirring the nitric acid solution of ammonium phospho-molybdate with a piece of tin metal in order to reduce the molybdenum and produce the blue color in making the test. The piece of tin also takes the place of a solution of stannous chloride and thus simplifies the equipment.

This test for water-soluble phosphorus is relatively accurate, and easily and rapidly applied in the field. No glassware is required for the tests other than the reagent containers fitted with droppers; hence, the necessity of washing dishes in the field, and the danger of contaminating tests are entirely eliminated. In pure solutions of sodium phosphate, the test is sensitive to one-fourth part of phosphorus in one million parts of water. The test is also sensitive to arsenic in the form of arsenate, which may interfere with its use on soils where arsenical sprays have been used in the control of crop insects.

Materials Required for the Test

1. Waxed papers—These papers are strips of white, paraffined paper about three-fourths of an inch wide and three and one-half inches long. They may be cut from a medium weight paraffined paper or from sheets of paper commonly known to the paper trade as bread wrapper stock.

2. Water—Tap or well water is preferable to distilled water because the slight flocculating effect of well water aids in obtaining clear water extracts of the soils to be tested. The water used for extracting the soil samples in making the phosphorus test must be free from phosphorus and in order to be sure of this point, the operator should make a blank test on it as outlined in this bulletin under the heading blank tests. A 150 cc. bottle fitted with a rubber stopper and pipette dropper is suitable for handling the water in making the phosphorus tests.

3. Molybdate reagent—This reagent is made by dissolving five grams of ammonium molybdate, chemically pure and free from phosphorus and arsenic, in 50 cc. of distilled water, heating gently if necessary. Then, pour this solution slowly with stirring, into 50 cc. of pure, concentrated nitric acid which must also be free from phosphorus and arsenic. Finally, dilute the mixture with 100 cc. of distilled water. It is also necessary to run a blank test on this reagent at regular intervals of time. Should a blue color be obtained in a blank test, add 3-5 cc. more of the nitric acid to the total quantity of reagent and in case the blue color is still apparent in a blank test, it is best to discard the whole quantity of reagent and make up a fresh supply. This molybdate reagent is a highly corrosive solution and must not come in contact with any substance liable to contain phosphorus. A suitable container for the molybdate reagent is a glass dropping bottle of about 30 cc. capacity fitted with a ground-in glass pipette.

4. Tin pencil—The tin pencil is a rod of pure tin about three-sixteenths inch in diameter and three or four inches long pointed on one end like a slate pencil. To make the tin pencil select a piece of glass tubing of suitable bore about six inches long and draw one end out to a capillary and turn the capillary sharply upward. Turn the other end

of the tube upward also and flare the opening outward to facilitate pouring. Fasten the tube in a metal support with the bent ends upward, melt the tin in a suitable dish, heat the glass tube quite hot and then pour in the molten tin. After cooling break the glass away from the tin and file the metal to the desired shape.

5. Color chart—The color chart used by the author was made by comparing the colors obtained by testing phosphorus solutions of known concentrations as outlined under the heading calibrating the test, with the color blocks found in Ridgway's book (2). The following colors were selected as representing as nearly as possible those obtained by the actual test.

Phosphorus concentration	Color name	Book plate No.
0.5 parts per million	Etain blue	Plate XX
1.0 parts per million	Beryl blue	Plate VIII
2.0 parts per million	Luminere blue	Plate XX
3.0 parts per million	Calamine blue	Plate VIII
4.0 parts per million	Cendre blue	Plate VIII
7.0 parts per million	Motmot blue	Plate XX
10.0 parts per million	Italian blue	Plate VIII
15.0 parts per million	Oxide blue	Plate VIII

The above named color blocks were obtained from the publishers of Ridgway's book and portions of them were mounted on a piece of cardboard which was carried in an envelope to protect the colors from light.

If the soil extract is not clear and colorless, the color developed in making the phosphorus test may have a slight greenish tint, hence, clear soil extracts should be obtained whenever possible.

Method of Making Blank Tests

Blank test on molybdate reagent—Place a drop of the molybdate reagent on a piece of the waxed paper. Add to this drop of reagent an equal sized drop of distilled water. Mix the two drops by stirring with the corner of another piece of the waxed paper and then stir the mixture with the sharp end of the tin pencil for about 10 seconds. If no blue color is observed the reagent is suitable for use. In case a faint blue color develops, proceed as directed under molybdate reagent. After making a test, always wipe the tin pencil on a cloth and scrape the point bright by means of a knife blade or spatula in preparation for the next test.

Blank test on water—Proceed as outlined for blank test on the molybdate reagent except use the well or tap water in place of the distilled water. Should a blue color develop in this blank test, the water is not suitable for making water extracts of soils for the phosphorus test.

2. Color Standards and Nomenclature. Ridgway, R. A. Hoen & Company, Baltimore, Maryland.

Method of Performing the Test

Fold a piece of the waxed paper once lengthwise and open to form a trough. Hold the folded paper between the thumb and forefinger of the left hand. With a knife blade, or small spatula, place some of the soil to be tested in the end of the paper trough close to the hand and then push the soil slightly away from the hand with the point of the knife blade, or the tin pencil, in order to make a cavity behind the soil sample to receive the water used for extracting the soil. The soil sample should fill the paper trough to the top edges and extend about three-quarters of an inch lengthwise on the paper. The soil should be mellow and friable and placed on the paper in a loose condition. During the testing operation, care must be taken not to mix or puddle the soil in any way with the water.

Drop the water into the paper trough back of the soil sample, slowly and carefully, allowing the soil to take up the water drop by drop, and controlling the movement of the water through the soil sample by tipping the open end of the paper slightly downward. The water must move slowly through the soil, not over or around it, otherwise clear extracts may not be obtained. When the clear soil extract appears at the outer or lower end of the soil sample, it is separated from the soil mass by touching the edge of the drop with the tip of the tin pencil and drawing a portion away to the outer end of the paper. Several of these drawing-out operations may be necessary in order to obtain a sufficient amount of the clear extract for making the test. When about a drop of the soil extract has been obtained and is held on the outer end of the paper, draw the drop off again onto a flat piece of the waxed paper. This second drawing operation aids in obtaining clearer soil extracts. Add to the drop of soil extract on the flat piece of paper an equal quantity of the molybdate reagent, these quantities can be estimated in drops with a little practice, and mix by stirring with the corner of a piece of the waxed paper, and then stir with the tip of the tin pencil for about 10 seconds. If phosphorus is present in the soil extract, within the accuracy of the test, a blue color develops and the intensity of this blue color is a measure of the quantity of phosphorus present in the soil extract up to the maximum color obtainable from the reaction.

The maximum intensity of this blue color develops in a short time, and then the color gradually fades out. If a comparison of two or several soil samples is desired, the extracts may all be obtained at first, and the molybdate reagent added and the blue color developed in all of the extracts at nearly the same time. In making comparative tests, approximately the same quantity of each soil sample should be taken. A slight turbidity of the soil extract does not seriously affect the test; but the strongly acid molybdate reagent must not come in contact with the soil sample or small detached particles of the soil. The described technic works well on all soils except plastic clays, and sometimes great care is necessary in order to obtain clear extracts from highly deflocculated muck soils.

In the case of dry muck soils not easily wet with water, the dry muck is stirred back into the water with the point of the tin pencil in the extracting operation until the soil is wet, ending this operation with the least possible quantity of water. Then push the wet soil forward on the paper, add a drop or two more of water back of the soil and complete the extraction.

Calibrating the Test

In order to place the phosphorus test on a quantitative basis, it was calibrated by testing solutions of known phosphorus content. A standard solution containing 100 parts per million of phosphorus was first made up by dissolving 0.4577 grams of pure di-sodium phosphate in distilled water and then diluting to one liter. From this standard solution, other solutions were prepared containing one-half, one, two, three, four, or more parts per million, respectively, of phosphorus by careful dilutions of aliquot portions. These solutions were then tested for phosphorus according to the prescribed technic for performing the test. The colors produced were compared with the color blocks in Ridgway's book in order to select the proper shades of color to represent, quantitatively, the amount of phosphorus to be found in unknown solutions or soil extracts.

Practical Application of the Test

When an investigator attempts to adapt a new test for the purpose of gathering information about soils, he is confronted with the difficulty of making suitable correlations between test results and the other factors susceptible to control measures. Due to the complex nature of soils, and to the present lack of knowledge concerning the chemical constitution of them, test results are sometimes obtained which can not be explained on the basis of the data at hand, and this situation demands a certain knowledge of the soil and cropping conditions under which the test has been applied. Experience gained from using this phosphorus test under field conditions has brought to light some of the difficulties connected with its use and some precautions must be observed if the test fulfills the expectations which may be placed upon it.

During the past three crop seasons, many hundreds of tests have been made on field soils with this phosphorus test, more particularly with the idea of developing a suitable technic for it and of determining its application and limitations. Tests have been made on several soil types and on fertilized and unfertilized fertility test plats both on mineral and organic soils. The results obtained to date indicate that the test can be used successfully in several lines of research pertaining to soil phosphorus and that useful information can be obtained with it relative to the application of phosphorus fertilizers to soils.

A low phosphorus test may be obtained under a luxuriantly growing crop which covers the ground, and the test can not be taken as proof that the crop is not getting a supply of phosphorus. A crop exerts a certain demand on a soil for its nutrient elements and this draft on the soil may exhaust the available supply of nutrients or take them up as fast as they become soluble. From this standpoint, it is probably not illogical to assume that a crop can obtain a sufficient supply of nutrient elements from a soil in which only small quantities are available. In cases of this kind, the power of the soil to supply phosphorus to the crop is an important soil fertility question, and it is also significant to this purpose to know if the soil gives a relatively high test for phosphorus before the crop is established, and if the soil recuperates rapidly from the phosphorus exhaustion after harvest. For this reason, it is believed that a test for plant nutrients should be applied periodically throughout the whole crop season. These statements apply, however, more particularly to field crops than to intensive cropping systems where large quantities of fertilizers are used.

Tests obtained from the use of a micro-chemical test of this kind can not be correlated directly with crop response to fertilizers except over the range in which the element in question is limiting. If some other element, or factor, is the limiting one, then a test for one nutrient element can not be used as an indicator of crop response. On the other hand, if relatively high phosphorus tests are obtained on a soil, and the crop yield is low, these results may be taken as an indication that some factor other than phosphorus is limiting crop growth.

An important matter in studies of this kind is the time and place of taking the soil sample for testing. Soils may vary considerably within short distances in their content of water-soluble phosphorus, and a knowledge of the possibilities for variation in this respect is requisite for good results. It was found that some soils gave higher phosphorus tests when dry than when wet. The drying of the soil, in these cases, caused phosphorus to become more soluble, which is thought to be due to changes in the soil system induced by the evaporation of water. It was found, also, that during periods of drying weather more soluble phosphorus could be obtained at the soil surface than in the soil immediately beneath the surface, and that the salt incrustations commonly found on soil surfaces always gave tests for soluble phosphorus. Evidently, some of the soluble soil phosphorus is brought to the surface and deposited there during periods of drying weather, and is dissolved and washed into the soil again by rains. The water-soluble phosphorus content of soils is influenced by decaying plants, droppings from animals, manure piles, burning of brush heaps, forest fires, and, as before mentioned, factors which change soil structure. If the testing is to be done after fertilizer applications, the method of applying the fertilizer is important to the manner of taking soil samples for the test. The operator should know, or attempt to discover if the fertilizer has been broadcasted, drilled in the row or beside the row, placed above or below the seed, or checked in hills. Thorough examination of any situation is necessary in order to obtain data that may be interpreted to practical advantage.

SOLUBLE PHOSPHORUS IN FIELD SOILS AS INFLUENCED BY PHOSPHORUS FERTILIZERS

Miscellaneous Field Tests

Method

In carrying out this phase of the work, it was thought best to follow the policy of testing soil from numerous situations in the field rather than to study a few soils intensively. Accordingly, nearly all of the phosphorus tests were made on station fertility plats and on cooperative experiment fields located in different parts of the State. By following this plan, the investigation covered a number of important Michigan soil types. The phosphorus tests were all made in the field on samples taken from dry, surface soils during a period of drying weather. Care was taken to select comparable situations for making the phosphorus test in order to exclude the possibility of the test results being influenced by the accidental factors discussed in the first part of this bulletin. In selecting these situations and in taking samples for the tests, attention was paid to the method of fertilizer application. Where broadcast applications of fertilizers were made, the samples were taken midway between crop rows, but in the case of drilled or row applications of fertilizers, the samples were selected from positions directly over the fertilizers.

Phosphorus tests were made on the water extracts of the soil samples according to the method previously outlined and the tests on the acid extracts were made in the same manner except that a dilute nitric acid solution containing four cc. of nitric acid per liter of water was used in place of water for extracting the soils.

In all the tables of this bulletin, a negative (—) sign indicates a blank test, or that no phosphorus was found in the soil extract, and a positive (+) sign denotes a positive test for phosphorus but a quantity less than 0.5 part per million.

Discussion of Table I

The results of the phosphorus test on water and acid extracts compare favorably with respect to order of quantity of phosphorus found, but the results obtained on the acid extracts are higher in magnitude than those of the water extracts. Before the investigation was completed, however, it was concluded that the phosphorus test results on water extracts corresponded more closely to the soil phosphorus available to crops than did those on the acid extracts, hence, the use of the dilute acid for making soil extracts was discontinued.

On soils having a low power to revert soluble phosphorus of the fertilizers to insoluble forms, differences were obtained in the soluble phosphorus content of soils between check plats and fertilized plats, and also between plots to which different amounts of fertilizers had been applied. In the case of soils having a high reverting power for phosphorus, however, a certain amount of fertilizer was required before definite phosphorus test results were obtained.

It is evident from these results that at least a part of the soil revert-

Table 1.—Phosphorus tests on fertilized and unfertilized soils. Test results in parts per million in soil extracts. All tests were made on the dry surface soil.

Soil No., type and fertilizer	Rate per A.	Crop	Phosphorus water extract	Phosphorus acid extract	Remarks
1. Hillsdale sandy loam	Ck.	Corn	+	2.0	Previously fertilized.
0-20-0	250 lbs.	Corn	0.5	4.0	Broadcast.
0-20-0	250 lbs.	Corn	0.5	4.0	Broadcast.
	Ck.	Potatoes	—	0.5	
2-12-6	500 lbs.	Potatoes	+	1.0	Broadcast.
	Ck.	Oats	+	0.5	
2-12-6	250 lbs.	Oats	+	1.0	Drilled, previously fertilized and limed.
	Ck.	Barley	+	0.5	
2-16-2	200 lbs.	Barley	+	0.5	Drilled, previously fertilized and limed,
2-16-2	200 lbs.	Oats	0.5	2.0	Drilled, previously fertilized and limed.
2. Coloma sand	Ck.	Corn	0.5	2.0	
0-20-0	250 lbs.	Corn	1.0	10.0	Broadcast.
0-20-0	500 lbs.	Corn	2.0	15.0	Broadcast.
3. Kewanee sandy loam	Ck.	Potatoes	1.0	3.0	
2-16-6	250 lbs.	Potatoes	1.0	4.0	Broadcast.
2-16-6	500 lbs.	Potatoes	1.0	4.0	Broadcast.
2-16-6	1000 lbs.	Potatoes	2.0	7.0	Broadcast.
4. Muck	Ck.	Onions	—	0.5	
0-16-0	250 lbs.	Onions	+	0.5	Broadcast.
0-16-0	500 lbs.	Onions	0.5	1.0	Broadcast.
0-16-0	750 lbs.	Onions	1.0	2.0	Broadcast.
0-16-0	750 lbs.	Onions	2.0	3.0	Broadcast. 750 lbs. KCl.
5. Kewanee sandy loam	Ck.	Potatoes	1.0	3.0	
2-16-6	200 lbs.	Potatoes	1.0	4.0	Broadcast.
2-16-6	400 lbs.	Potatoes	2.0	7.0	Broadcast.
2-16-6	600 lbs.	Potatoes	2.0	10.0	Broadcast.
2-16-6	800 lbs.	Potatoes	2.0	10.0	Broadcast.
6. Muck	Ck.	Onions	2.0	4.0	Previously fertilized.
0-16-0	500 lbs.	Onions	3.0	7.0	Broadcast.
7. Onaway sandy loam	Ck.	Potatoes	+	2.0	
2-16-6	250 lbs.	Potatoes	0.5	3.0	Broadcast.
2-16-6	500 lbs.	Potatoes	1.0	3.0	Broadcast.
2-16-6	1000 lbs.	Potatoes	2.0	5.0	Broadcast.
8. Onaway sandy loam	Ck.	Potatoes	+	2.0	
0-16-0	800 lbs.	Potatoes	0.5	3.0	Broadcast.
9. Muck	Ck.	Onions	0.5	2.0	
4-4-16	1200 lbs.	Onions	2.0	7.0	Broadcast.
4-8-16	1200 lbs.	Onions	4.0	7.0	Broadcast.
10. Roselawn sandy loam	Ck.	Potatoes	+	2.0	
2-16-6	375 lbs.	Potatoes	0.5	3.0	Broadcast.
2-16-6	750 lbs.	Potatoes	1.0	10.0	Broadcast.
2-16-6	1500 lbs.	Potatoes	2.0	7.0	Broadcast.
11. Roselawn sandy loam	Ck.	Potatoes	+	2.0	
0-16-0	800 lbs.	Potatoes	0.5	3.0	Broadcast.
12. Muck	Ck.	Potatoes	1.0	2.0	
0-8-0	600 lbs.	Potatoes	2.0	3.0	Broadcast.
13. Miami loam	Ck.	Potatoes	—	0.5	
2-16-0	250 lbs.	Potatoes	+	1.0	Broadcast.
2-16-0	500 lbs.	Potatoes	0.5	2.0	Broadcast.
2-16-0	1000 lbs.	Potatoes	1.0	3.0	Broadcast.
2-16-6	250 lbs.	Potatoes	+	0.5	Broadcast.
2-16-6	500 lbs.	Potatoes	0.5	1.0	Broadcast.
2-16-6	1000 lbs.	Potatoes	1.0	2.0	Broadcast.
14. Coloma sand	Ck.	Corn	+	0.5	
0-20-0	250 lbs.	Corn	0.5	1.0	Broadcast.
0-20-0	500 lbs.	Corn	1.0	2.0	Broadcast.
15. Hillsdale sandy loam	Ck.	Corn	—	+	
0-20-0	250 lbs.	Corn	+	2.0	Broadcast.
	Ck.	Corn	—	+	
0-20-0	250 lbs.	Corn	+	1.0	Broadcast.
	Ck.	Alfalfa	—	+	
0-20-0	250 lbs.	Alfalfa	+	0.5	Broadcast.
	Ck.	Oats	—	—	
0-20-0	250 lbs.	Oats	0.5	2.0	Drilled.
	Ck.	Wheat	—	+	
Anaconda	87½ lbs.	Wheat	+	1.0	Drilled.

Table 1.—Continued

Soil No., type and fertilizer	Rate per A.	Crop	Phosphorus water extract	Phosphorus acid extract	Remarks
16. Kewanee sandy loam	Ck.	Corn	—	—	Broadcast.
0-16-0	250 lbs.	Corn	—	+	Broadcast.
0-16-0	500 lbs.	Corn	0.5	0.5	Broadcast.
0-16-0	750 lbs.	Corn	0.5	1.0	Broadcast.
17. Muck	Ck.	Carrots	+	....	Midway between rows.
0-8-24	200 lbs.	Carrots	0.5	....	Broadcast.
0-8-24	200 lbs.	Carrots	3.0	....	Row application.
0-8-24	200 lbs.	Carrots	3.0	....	Applied under seed.
0-8-24	1000 lbs.	Carrots	3.0	....	Broadcast.
18. Muck	Ck.	Onions	0.5	....	Previously fertilized.
0-8-24	600 lbs.	Onions	2.0	....	Applied under row.
19. Muck	Ck.	Potatoes	0.5	....	
0-8-24	800 lbs.	Potatoes	2.0	....	Broadcast.
20. Muck	Ck.	Onions	2.0	....	Previously fertilized.
4-4-16	1200 lbs.	Onions	2.0	....	Broadcast.
4-8-16	1200 lbs.	Onions	3.0	....	Broadcast.
4-8-16	1200 lbs.	Onions	3.0	....	Broadcast, P in Basic Slag.
4-8-16	1200 lbs.	Onions	2.0	....	Broadcast, P in Bone Meal.
4-8-16	1200 lbs.	Onions	3.0	....	Broadcast, P in Ca $(H_2PO_4)_2$.
4-8-16	1200 lbs.	Onions	3.0	....	Broadcast, P in Ca HPO_4).
21. Muck	Ck.	Peppermint	2.0	....	
0-0-24	800 lbs.	Peppermint	2.0	....	Broadcast.
0-8-0	800 lbs.	Peppermint	3.0	....	Broadcast.
0-8-24	800 lbs.	Peppermint	3.0	....	Broadcast.
22. Muck	Ck.	Peppermint	2.0	....	
0-0-24	500 lbs.	Peppermint	3.0	....	Broadcast.
0-8-0	500 lbs.	Peppermint	3.0	....	Broadcast.
23. Waukesha silt loam	Ck.	Alfalfa	+	....	
0-16-0	200 lbs.	Alfalfa	+	....	Broadcast.
Anaconda	80 lbs.	Alfalfa	+	....	Broadcast.
Rock phosphate	1000 lbs.	Alfalfa	+	....	Broadcast.
Rock phosphate	1600 lbs.	Alfalfa	0.5	....	Broadcast.
Rock phosphate	2000 lbs.	Alfalfa	0.5	....	Broadcast.
24. Fox sandy loam	Ck.	Potatoes	+	....	
0-16-0	200 lbs.	Potatoes	0.5	....	Broadcast, 6 applications.
Rock phosphate	1000 lbs.	Potatoes	1.0	....	Broadcast.
0-16-0	400 lbs.	Potatoes	0.5	....	Broadcast.
Anaconda	37 lbs.	Potatoes	+	....	Broadcast.
Anaconda	74 lbs.	Potatoes	+	....	Broadcast.
	Ck.	Oats	+	....	
Rock phosphate	700 lbs.	Oats	0.5	....	Broadcast, 4 applications.
Rock phosphate	1500 lbs.	Oats	1.0	....	Broadcast, 4 applications.
Rock phosphate	2000 lbs.	Oats	1.0	....	Broadcast, 4 applications.
25. Fox sandy loam	Ck.	Alfalfa	—	....	
Anaconda	84 lbs.	Alfalfa	+	....	Broadcast, + 100 lbs. KCl, 2 applications.
0-16-0	200 lbs.	Alfalfa	+	....	Broadcast, + 50 lbs. KCl, 2 applications.
0-16-0	200 lbs.	Alfalfa	+	....	Broadcast, 2 applications.
0-16-0	200 lbs.	Alfalfa	+	....	Broadcast, + 100 lbs. KCl + 50 lbs., Na NO_3, 2 applications.
0-16-0	200 lbs.	Alfalfa	+	....	Broadcast, + 100 lbs. KCl, 2 applications.
0-16-0	220 lbs.	Alfalfa	+	....	Broadcast, + 110 lbs. KCl.
0-16-0	330 lbs.	Alfalfa	+	....	Broadcast, + 165 lbs. KCl.
0-16-0	400 lbs.	Alfalfa	0.5	....	Broadcast, 2 applications.
0-16-0	660 lbs.	Alfalfa	2.0	....	Broadcast, + 330 lbs. KCl.
Rock phosphate	1500 lbs.	Alfalfa	0.5	....	Broadcast.
26. Muck	Ck.	Celery	+	....	
0-8-24	1500 lbs.	Celery	1.0	....	Broadcast.
0-8-24	1500 lbs.	Celery	0.5	....	Broadcast, P in Basic Slag.
27. Brookston silt loam	Ck.	Sugar beets	+	....	
0-16-0	250 lbs.	Sugar beets	0.5	....	Broadcast.
0-16-0	500 lbs.	Sugar beets	1.0	....	Broadcast.
0-16-0	500 lbs.	Sugar beets	2.0	....	Broadcast, + 200 lbs. KCl.
0-16-0	250 lbs.	Sugar beets	1.0	....	Broadcast, + 200 lbs. KCl.
0-16-0	800 lbs.	Sugar beets	2.0	....	Broadcast.
28. Muck	Ck.	Onions	0.5	....	
4-4-16	1200 lbs.	Onions	1.0	....	Broadcast.
4-8-16	1200 lbs.	Onions	1.0	....	Broadcast, P in Basic Slag.
4-10-16	1200 lbs.	Onions	2.0	....	Broadcast.
4-8-16	560 lbs.	Onions	3.0	....	Row application.

Table 1.—Continued

Soil No., type and fertilizer	Rate per A.	Crop	Phosphorus water extract	Phosphorus acid extract	Remarks
29. Brookston silt loam	Ck.	Corn	+	....	
0-16-0	250 lbs.	Corn	1.0	....	Broadcast.
0-16-0	250 lbs.	Corn	2.0	....	Broadcast, + 100 lbs. $NaNO_3$, + 50 lbs. KCl
Anaconda	84 lbs.	Corn	1.0	....	Broadcast.
Rock phosphate	1000 lbs.	Corn	1.0	....	Broadcast.
30. Kewanee sandy loam	Ck.	Potatoes	—	....	
Anaconda	84 lbs.	Potatoes	0.5	....	Broadcast.
31. Coloma sand	Ck.	Potatoes	+	....	
Anaconda	84 lbs.	Potatoes	1.0	....	Broadcast.
Anaconda	84 lbs.	Potatoes	1.0	....	Broadcast, + 100 lbs. $NaNO_3$ + 50 lbs. KCl
32. Napanee silt loam	Ck.	Sugar beets	+	....	
0-16-0	200 lbs.	Sugar beets	1.0	....	Broadcast.
Anaconda	100 lbs.	Sugar beets	1.0	....	Broadcast.
33. Miami loam	Ck.	Potatoes	+	....	
0-16-0	250 lbs.	Potatoes	1.0	....	Broadcast.
34. Muck	Ck.	Peppermint	0.5	....	
0-8-16	500 lbs.	Peppermint	1.0	....	Broadcast.
35. Newton sand	Ck.	Onions	+	....	
0-8-16	1200 lbs.	Onions	1.0	....	Broadcast.
36. Muck	Ck.	Onions	0.5	....	
0-0-16	1200 lbs.	Onions	0.5	....	Broadcast.
2-4-16	1200 lbs.	Onions	1.0	....	Broadcast.
2-6-16	1200 lbs.	Onions	1.0	....	Broadcast.
2-8-16	1200 lbs.	Onions	1.0	....	Broadcast.
2-8-16	600 lbs.	Onions	3.0	....	Row application.
37. Newton sand	Ck.	Onions	0.5	....	
0-8-16	1200 lbs.	Onions	1.0	....	Broadcast.
38. Muck	Ck.	Sugar beets	0.5	....	
0-8-16	500 lbs.	Sugar beets	1.0	....	Broadcast.
39. Muck	Ck.	Corn	—	....	
0-16-0	100 lbs.	Corn	—	....	Broadcast.
0-16-0	200 lbs.	Corn	—	....	Broadcast.
0-16-0	300 lbs.	Corn	1.0	....	Broadcast.
0-16-0	300 lbs.	Corn	2.0	....	Broadcast, + 1000 lbs. Salt.
40. Muck	Ck.	Celery	0.5	....	
0-8-16	1200 lbs.	Celery	1.0	....	Broadcast.
0-8-0	1200 lbs.	Celery	1.0	....	Broadcast.
0-8-0	1200 lbs.	Celery	2.0	....	Broadcast, + 1000 lbs. Salt.
0-8-0	1200 lbs.	Celery	0.5	....	Broadcast, P in Basic Slag.
Ashes	1000 lbs.	Celery	0.5	....	Broadcast.
41. Muck	Ck.	Peppermint	+	....	
0-8-0	500 lbs.	Peppermint	0.5	....	Broadcast.
2-8-16	500 lbs.	Peppermint	0.5	....	Broadcast.
42. Muck	Ck.	Peppermint	—	....	
2-8-16	500 lbs.	Peppermint	0.5	....	Broadcast.
43. Coloma sand	Ck.	Corn	—	....	
Anaconda	84 lbs.	Corn	+	....	Broadcast.
44. Kewanee sandy loam	Ck.	Corn	—	....	
Anaconda	84 lbs.	Corn	+	....	Broadcast.
45. Miami loam	Ck.	Sugar beets	0.5	....	
0-16-0	250 lbs.	Sugar beets	1.0	....	Broadcast, + 100 lbs. $NaNO_3$, + 50 lbs. KCl
46. Brookston silt loam	Ck.	Sugar beets	0.5	....	
Anaconda	84 lbs.	Corn	+	....	Broadcast.
45. Miami loam	Ck.	Sugar beets	0.5	....	
0-16-0	250 lbs.	Sugar beets	1.0	....	Broadcsat, + 100 lbs. $NaNO_3$, + 50 lbs. KCl
46. Brookston silt loam	Ck.	Sugar beets	0.5	....	
0-16-0	250 lbs.	Sugar beets	1.0	....	Broadcast, + 100 lbs. $NaNO_3$, + 50 lbs. KCl
47. Brookston silt loam	Ck.	Sugar beets	—	....	
0-16-0	250 lbs.	Sugar beets	—	....	Broadcast.
0-16-0	500 lbs.	Sugar beets	0.5	....	Broadcast.

ing power must be satisfied before phosphorus can exist in the soil solution in appreciable amounts, and the quantity of a phosphorus fertilizer required to meet this condition depends upon the nature of the soil in this respect.

It is apparent from the results in Table I that large applications of KCl, $NaNO_3$, and NaCl increase the solubility of phosphorus applied with these fertilizers, and it is thought that this effect is more marked on soils which have a low phosphorus reverting power.

The solubility of phosphorus in soils undoubtedly varies with the different kinds of phosphorus fertilizers applied to them, but the data presented here are considered insufficient to prove this point fully.

Higher test results were obtained from row applications of fertilizers than from broadcast applications, even where smaller amounts of fertilizer were applied on a per acre basis, except in cases where the soil contained comparatively large quantities of soluble phosphorus from heavy applications of fertilizers.

DEPTH-DISTRIBUTION OF WATER SOLUBLE PHOSPHORUS IN FERTILIZED SOILS

1. FERTILIZERS APPLIED AT DIFFERENT DEPTHS

Method of Study

For this investigation, four different soils were selected in locations sufficiently close together to insure that rainfall and soil drying conditions would be nearly the same. All of these soils were located within an area of one square mile. The experimental plats were established by measuring off a small fraction of an acre and applying the requisite aliquot part of fertilizer at the rate of 1,000 pounds per acre of 20 per cent superphosphate. In the cases of depth applications of the fertilizer, the surface soil was removed to the desired depth, the fertilizer applied, and the soil replaced as nearly as possible in its original position. All of the plats were then left in a natural condition, that is, the soil and plant cover was undisturbed until the plats were sampled later in the season.

Samples were taken from the several locations by digging a hole with one perpendicular side into the soil to the desired depth and, commencing at the bottom of this perpendicular side, samples were taken by means of a spatula representing inch depths up to the soil surface, and the surface, or 0-depth sample, was taken directly from the surface of the soil. As these soil samples contained different amounts of water, they were placed in small paper sacks in the field and finally brought to the laboratory where they were dried in the air before testing them for phosphorus. The results of this experiment are shown in Table 2.

Discussion of Table 2

The results show that the vertical distribution of water soluble phosphorus is the greatest in the Coloma sand soil. This soil has the great-

Table 2.—Depth—Distribution of water soluble phosphorus in four soil types. Phosphorus results in parts per million on soil extracts. Rate of fertilizer application, 1,000 lbs. per acre of 20 per cent superphosphate.

Soil Depth in inches.	1. Coloma sand—Established May 5, 1928. Sampled June 28, 1928.				2. Hillsdale sandy loam—Established May 1, 1928. Sampled July 12, 1928.			
	Ck.	Depth of fertilizer application			Ck.	Depth of fertilizer application		
		0 in.	4 in.	8 in.		0 in.	4 in.	7 in.
0	0.5	3.0	2.0	1.0	—	5.0	0.5	+
1		4.0	3.0	1.0		+	0.5	+
2		4.0	3.0	2.0		—	0.5	+
3		4.0	4.0	2.0		—	1.0	+
4	1.0	3.0	12.0	2.0	+	—	3.0	+
5		2.0	10.0	3.0		—	1.0	0.5
6		2.0	8.0	4.0	—	—	0.5	0.5
7		1.0	5.0	4.0		—	+	7.0
8	1.0	1.0	4.0	10.0		—	—	1.0
9		1.0	2.0	7.0				—
10		1.0	1.0	5.0		—	—	—
11		1.0	1.0	4.0				
12		0.5	1.0	3.0	—	—	—	—
13		0.5	0.5	2.0				
14		0.5	0.5	2.0		—	—	—
15	0.5	0.5	0.5	1.0				

Table 2.—Continued

Soil depth in inches	3. Brookland silt loam—Established May 10, 1928. Sampled July 13, 1928.				4. Muck—Established May 12, 1928. Sampled July 12, 1928.			
	Ck.	Depth of fertilizer application			Ck.	Depth of fertilizer application		
		0 in.	4 in.	7 in.		0 in.	3 in.	6 in.
0	+	3.0	+	+	+	15.0	0.5	+
1		1.0	+	+		3.0	0.5	+
2		0.5	0.5	+		1.0	0.5	0.5
3	+	+	0.5	+		1.0	4.0	0.5
4		+	2.0	+	+	0.5	3.0	0.5
5		+	0.5	0.5		+	0.5	1.0
6	+	+	+	0.5		+	+	10.0
7			+	3.0		+	+	3.0
8			+	1.0	+	+	+	1.0
9	+	+	+	0.5				0.5
10				0.5		+	+	+
11				+				
12	+	+	+	+		+	+	+
13								
14					+	+	+	+

est degree of freedom of water movement and the lowest phosphorus reverting power of the four soils under investigation, and these facts undoubtedly explain why more of the applied phosphorus remains soluble and moves more freely in it than in the other soils. Soluble phosphorus placed on the surface of soils moves downward. But when it is placed at various depths in soils both an upward and downward movement may be indicated by the phosphorus test results. The greater the depth of fertilizer placement, however, the less is the probability of the soluble phosphorus coming to the soil surface in one season, especially if the reverting power of the soil for phosphorus is high. In fact, it is believed possible to place a phosphorus fertilizer in a soil at a depth where practically no upward movement of soluble phosphorus can be indicated in the same season.

The results obtained from the surface application of superphosphate on the Hillsdale sandy loam soil show that the downward movement of soluble phosphorus from the surface may be negligible in some soils. In these soils the distribution of applied fertilizer would be limited to the mechanical mixing brought about by tillage implements, and the injury to crop roots growing in the surface zone of soils of this nature by summer cultivation would lower the efficiency of broadcast applications of fertilizers.

Upward and downward movements of soluble phosphorus in soils are closely related to soil water movements, as the magnitude of phosphorus movement in these soils can be explained in no other way. It is apparent that soluble phosphorus moves upward in soils when they are drying and that the downward movement of this element is due chiefly to percolating water. As soils dry out, the upward movement of phosphorus gradually extends deeper and deeper into the soil and the ultimate soil depth affected depends on the length of the period of drying weather and the soil factors influencing soil water movements. In case phosphorus fertilizer is placed below this limiting soil depth, no marked upward movement of soluble phosphorus can take place. So far as present observations extend, this limiting depth of upward movement of soil phosphorus lies deeper than the plowed portion of mineral soils, and is thought to coincide closely with the surface of the B soil horizon. On the other hand, the downward movement of soluble phosphorus in soils is relatively rapid, and, if the depth of downward movement of the phosphorus exceeds the limiting depth of the upward movement, a concentration of phosphorus may result at this point in soils of low reverting power or where large amounts of fertilizer have been applied. This concentrating process affecting the soluble materials of soils may partly account for the formation of the B horizon in mineral soils.

2. ROW APPLICATIONS OF PHOSPHORUS FERTILIZERS

Method of Sampling the Soils

In studying the distribution of soluble phosphorus in soils from row applications of phosphorus fertilizers, the method of sampling the soils was similar to that already given under subdivision one of this subject. A hole with a wide perpendicular side was dug into the soil across the row. Separate soil samples were taken out of this perpendicular side representing different soil depths under the row, and at certain distances on each side of the row as indicated in the headings of Table 3. Samples were also taken from check plats in each case. These soil samples were taken toward the end of the growing season, hence, the fertilizers had been in the soil from two and one-half to three months.

Discussion of Table 3

The results presented in this table were selected chiefly to show certain points of practical interest. Soils No. 1, 2, and 5 give results obtained from row applications of phosphorus fertilizers on soils having a high reverting power for soluble phosphorus; soil No. 5 received the largest application of fertilizer. Soils No. 3 and 4, however, have received heavy applications of fertilizers for a number of years, and their phosphorus reverting power has been satisfied, at least to a considerable extent, as comparatively large quantities of soluble phosphorus were found in them. Although soil No. 1 is a sandy soil, it can be seen from the results that the soluble phosphorus of the fertilizer applied to it moved very little in one season. This effect is considered due to the high reverting power of this soil for phosphorus. The crop yield from this row application, however, markedly exceeded the yield from an adjacent soil plat which received a broadcast application of the same amount and kind of fertilizer. Sweet clover was plowed under

Table 3.—Phosphorus test results from row applications of fertilizers. Phosphorus results in parts per million on the soil extract.

Soil depth	1. Fox sandy loam— 4-16-8 fertilizer, 500 lbs. per A. Placed 3 in. deep, 6 in. wide—Cabbage						2. Brookston silt loam— 4-16-4 fertilizer, 400 lbs. per A. Drilled with seed—Sugar beets.					
	Ck.	6 in.	3 in.	Row	3 in.	6 in.	Ck.	6 in.	3 in.	Row	3 in.	6 in.
0	+	+	+	+	+	+	+	+	+	+	0.5	0.5
1	...	+	+	+	+	+	...	...	...	...	...	...
2	...	+	+	0.5	+	+	+	+	+	+	+	+
3	+	+	4.0	3.0	5.0	+	...	...	...	...	...	...
4	...	+	+	+	+	+	+	+	+	0.5	+	+
5	...	...	...	+	...	...	...	...	...	...	...	...
6	...	+	+	+	+	+	+	+	+	+	+	+
7	...	...	...	0.5	...	...	...	...	...	...	...	...
8	0.5	...	0.5	0.5	+	...	+	...	...	+	...	...
9	...	...	...	...	...	...	...	...	...	...	...	...
10	...	...	...	+	...	...	+	...	...	+	...	...

Soil depth	3. Muck— 0-8-24 fertilizer 1200 lbs. per A. •Placed 2 in. deep—Celery.						4. Muck— 0-8-24 fertilizer 1800 lbs. per A. Placed 2 in. deep—Celery.					
	Ck.	6 in.	3 in.	Row	3 in.	6 in.	Ck.	6 in.	3 in.	Row	3 in.	6 in.
0	1.0	1.0	0.5	2.0	1.0	1.0	4.0	4.0	3.0	4.0	4.0	3.0
1	...	...	...	2.0	...	...	...	...	...	...	...	...
2	...	1.0	0.5	3.0	3.0	0.5	7.0	5.0	4.0	15.0	4.0	4.0
3	...	...	...	2.0	...	...	...	...	...	...	...	...
4	1.0	1.0	0.5	2.0	2.0	1.0	3.0	4.0	5.0	7.0	5.0	3.0
5	...	...	...	2.0	...	...	...	...	...	...	...	...
6	...	1.0	2.0	2.0	+	+	3.0	2.0	2.0	3.0	3.0	3.0
7	...	...	...	—	...	...	...	...	...	...	...	...
8	...	0.5	2.0	—	—	—	3.0	1.0	0.5	0.5	1.0	1.0
9	...	...	...	—	...	...	...	...	...	...	...	...
10	+	...	...	—	...	...	1.0	...	+	+	0.5	...
11	...	...	...	—	...	...	...	...	...	...	...	...
12	...	...	...	—	...	...	0.5	...	...	+	...	...
13	...	...	...	...	...	...	...	...	...	...	...	...
14	...	...	...	...	...	...	+	...	...	+	...	...

Soil depth	5. Muck—4-8-16 fertilizer 800 lbs. per A.					
	Ck.	Above Seed	With seed	In row 1 in.	Under 2 in.	Seed 3 in.
(a) Onions:						
0	+	5.0	1.0	0.5	1.0	1.0
1	....	2.0	4.0	2.0	5.0	1.0
2	+	1.0	2.0	2.0	5.0	2.0
3	....	1.0	1.0	1.0	2.0	2.0
4	+	1.0	1.0	0.5	1.0	1.0
5	....	1.0	1.0	1.0	1.0	1.0
6	—	0.5	0.5	0.5	0.5	0.5
7	....	....	....	....	....	0.5
(b) Cauliflower:						
0	+	2.0	2.0	1.0	1.0	1.0
1	....	2.0	1.0	2.0	1.0	1.0
2	+	1.0	2.0	2.0	3.0	1.0
3	....	2.0	1.0	1.0	2.0	2.0
4	+	2.0	1.0	1.0	2.0	1.0
5	....	1.0	2.0	1.0	2.0	1.0
6	—	0.5	1.0	1.0	1.0	1.0
7	....	....	....	....	....	0.5

on this soil in the spring, which undoubtedly accounts for the higher phosphorus test results at the seven and eight inch depths.

In the case of soil No. 2, the phosphorus test results show that the applied phosphorus was not very soluble in it. The surface tests three and six inches on one side of the row are assumed to be due to the drawing of the fertilizer to this side in thinning the beets, and the test result at the four inch depth is thought to be accidental.

Measured by the crop yields, the row applications of fertilizers on soils 3 and 4 were not as effective as was observed in some other cases of row applications, probably due to the relatively high content of phosphorus present from prior applications of fertilizers. Two other points regarding these soils are worthy of mention. The low test results found on one side of the row in soil No. 3 are the result of the presence of a more impervious soil structure than occured on the other side of row; evidently, the phosphorus did not move into this soil region but was carried around it by the downward movement of the soil water. Another important point in this connection is, that although these soils have received large applications of fertilizers for a number of years, the soluble phosphorus in them is confined almost entirely to the plowed portion. While this fact was established for several muck soils, it does not apply to mineral soils. This shows that the downward movement of water is much more pronounced in mineral soils than in mucks.

Soil No. 5 represents a case where a large quantity of a phosphorus fertilizer was applied to a soil with a high reverting power for phosphorus. (Same soil as No. 5, Table 4.) The phosphorus moved downward, in all cases, to the depth of sampling, but the crops were injured where the fertilizer was placed too close to the seed.

MISCELLANEOUS DETERMINATIONS—AMOUNT AND MOVEMENT OF SOLUBLE PHOSPHORUS IN FERTILIZED SOILS

Method

The method followed in taking the soil samples for this part of the work was similar to that already outlined in the preceding part of this bulletin. Fertility test plats and cooperative experiments furnished the soil samples and these samples were all dried in the laboratory to a uniform moisture content before testing. The results are given in Table 4.

Discussion of Table 4

The figures presented in this table show, in general, the soil content and the distribution in depth, of water soluble phosphorus in several soils as a result of the application of different kinds and amounts of phosphatic fertilizers. An increase in the quantity of soluble phosphorus in soils is usually obtained by fertilizer additions. The magnitude of this increase and the depth of penetration of the soluble phosphorus, however, depend on several factors. In this connection, the factors of chief importance are considered to be: (1) the amount of fertilizer applied, (2) the reverting power of the soil, and (3) the freedom of water movements.

Soils No. 2, 3, 9, and 10 are examples of mineral soils in which the soluble phosphorus due to fertilization is contained within the plowed depth; while, in the case of soils No. 7 and 8, the soluble phosphorus has moved to lower levels. Soil No. 7 shows evidence of phosphorus concentration at the eight and 10 inch depth. All the muck soils, except No. 11d, which has had heavy applications of fertilizers for several years, retain their soluble phosphorus within the plowed layer.

Soil No. 1 has received three broadcast applications of fertilizer in five years, each application at the rate given as column headings in the table. In the year 1928, the plats of this experiment were growing alfalfa, and the 500 pound plat showed by far the best growth of this crop. The phosphorus tests on this plat averaged 1.0 part per million for the surface six inches of soil, but a total fertilizer application of 1,500 pounds per acre of 16 per cent superphosphate was required to bring the soil to this point.

In the case of soil No. 2, the broadcast application of 400 pounds per acre of 20 per cent superphosphate showed no more soluble phosphorus than the check plat and the soluble phosphorus lies deeply in the soil on the plat where this fertilizer was plowed under. The soluble phosphorus in this plat may be too deep to benefit young plants growing on it.

An interesting situation was found in connection with soil No. 3. The applied phosphorus was somewhat soluble in the surface layers of this soil but, at the soil depth in each plat where the first low phosphorus test is shown, there exists a brown layer of soil consisting chiefly, of soil grains partly covered with an iron-aluminum-organic coating and this brown layer of soil effectively stopped the downward

Table 4. Amount and Depth-Distribution of Soluble Phosphorus in Miscellaneous Fertilized Soils. Phosphorus results in parts per million on soil extracts. Soil depth in inches.

Soil depth	1. Fox sandy loam— Fertilizer—16% superphosphate—3 broadcast applications.					2. Brookston silt loam— Fertilizer—20% superphosphate, 400 lbs. per A.		
	Ck.	Rate per A.				Ck.	Plowed under	Broadcast
		100 lbs.	200 lbs.	300 lbs.	500 lbs.			
0	+	0.5	0.5	0.5	1.0	+	+	+
1		+	0.5	0.5	1.0			
2		+	0.5	0.5	1.0	+	+	+
3		+	0.5	0.5	1.0			
4	0.5	0.5	0.5	0.5	1.0	+	0.5	+
5		+	+	0.5	1.0			
6		+	+	0.5	1.0	+	+	+
7					1.0			
8						+	1.0	+
9	+	+	+	+	+			
10						+	1.0	+

Soil depth	3. Mancelona sandy loam— Fertilizer—20% superphosphate + KCl + Na No3—Broadcast application.						4. Fox sandy loam— Fertilizer—Rock phosphate 3000 lbs. per A.—Plowed four times.	
	Ck. 1	P-250 lbs. K-100 lbs.	P-600 lbs.	P-600 lbs. K-400 lbs.	Ck. 2	P-200 lbs. K-150 lbs. N-100 lbs.	Ck.	Phosphate
0	0.5	3.0	3.0	3.0	+	+	+	1.0
1	0.5	1.0	2.0	2.0		0.5		1.0
2	0.5	1.0	1.0	2.0	+	0.5		1.0
3		0.5	0.5	1.0		0.5	+	1.0
4	+	0.5	+	1.0	+	0.5		1.0
5								1.0
6		+	+	1.0		+		1.0
7								0.5
8	+	+	+	+	+	+	0.5	0.5
9								
10		+	+	+		+		+
11								
12	+	+	+	+	+	+	+	+

Soil depth	5. Muck— Fertilizer—16% superphosphate. Broadcast—7 applications. Rate per A.				6. Muck— Fertilizer—0-8-24. Broadcast application 1200 lbs. per A.	
	Ck.	250 lbs.	500 lbs.	750 lbs.	Ck.	Fertilizer
0	+	1.0	1.0	3.0	1.0	2.0
1						
2	+	+	0.5	1.0		2.0
3						
4	+	0.5	1.0	2.0	1.0	2.0
5						
6	–	–	–	–		2.0
7						
8	–	–	–	–		2.0
9						
10	–	–	–	–	+	+

Soil depth	7. Isabella sandy loam— Fertilizer—2-12-6—Broadcast application. Rate per A.+ 5 loads manure.					Rate per A.—No manure.			
	Ck.	250 lbs.	500 lbs.	1000 lbs.	1500 lbs.	250 lbs.	500 lbs.	1000 lbs.	1500 lbs.
0	0.5	1.0	2.0	3.0	4.0	1.0	2.0	2.0	3.0
1	...	0.5	1.0	2.0	3.0	0.5	1.0	1.0	3.0
2	+	0.5	1.0	1.0	2.0	0.5	1.0	1.0	2.0
3	...	0.5	1.0	2.0	2.0	0.5	1.0	2.0	2.0
4	+	0.5	1.0	2.0	2.0	0.5	0.5	1.0	1.0
5	...	0.5	0.5	1.0	1.0	0.5	1.0	0.5	0.5
6	+	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0
7	...	...	...	...	...	...	...	...	...
8	+	1.0	1.0	2.0	2.0	1.0	2.0	2.0	1.0
9	...	...	...	...	...	...	...	...	...
10	+	0.5	2.0	2.0	2.0	1.0	1.0	2.0	1.0

Soil depth	8. Berrien sand— Fertilizer—4-16-8 on tomatoes. Rate per A.—Around hills.				Rate per A.—Broadcast.		
	Ck.	400 lbs.	800 lbs.	1200 lbs.	400 lbs.	800 lbs.	1200 lbs.
0	0.5	0.5	1.0	3.0	0.5	1.0	3.0
1	...	0.5	2.0	2.0	0.5	0.5	2.0
2	0.5	0.5	2.0	5.0	0.5	0.5	1.0
3	...	0.5	1.0	3.0	0.5	1.0	1.0
4	0.5	1.0	1.0	2.0	0.5	1.0	1.0
5	...	1.0	1.0	1.0	0.5	1.0	1.0
6	0.5	0.5	0.5	0.5	0.5	0.5	1.0
7	...	0.5	0.5	0.5	0.5	0.5	1.0
8	0.5	0.5	0.5	0.5	0.5	0.5	0.5
9	...	...	...	...	...	...	...
10	0.5	0.5	0.5	0.5	0.5	0.5	0.5
11	...	...	...	...	...	...	...
12	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Soil depth	9. Miami loam— Fertilizer 20% superphosphate + 100 lbs. KCl + 100 lbs. Na NO_3. Soil sampled two years after fertilization. Rate of phosphate application.					
	Ck.	200 lbs.	400 lbs.	600 lbs.	800 lbs.	N + K
0	+	0.5	0.5	0.5	1.0	0.5
1	+	0.5	0.5	0.5	0.5	0.5
2	...	...	...	...	...	...
3	+	0.5	0.5	0.5	0.5	+
4	...	...	...	...	...	...
5	...	...	...	...	...	...
6	+	+	+	0.5	0.5	+
7	...	...	...	...	...	...
8	...	...	...	...	...	...
9	+	+	+	+	+	+

Soil depth	10. Hillsdale sandy loam—Fertilizer—4-16-8. Broadcast application—Rate per A.				11. Miscellaneous mucks—Fertilized several times with different amounts and kinds of fertilizers.			
	Ck.	400 lbs.	800 lbs.	1200 lbs.	(a)	(b)	(c)	(d)
0	+	0.5	1.0	2.0	3.0	4.0	2.0	5.0
1		0.5	0.5	2.0	4.0	3.0	1.0	5.0
2	0.5	0.5	0.5	0.5	2.0	4.0	2.0	5.0
3		0.5	0.5	0.5	1.0	3.0	2.0	5.0
4	+	0.5	0.5	0.5	0.5	2.0	2.0	5.0
5		0.5	0.5	0.5	0.5	0.5	2.0	5.0
6	+	0.5	0.5	0.5	+	–	1.0	7.0
7		+	+	+				
8	+	+	+	+	+	–	4 (ashes)	1.0
9								
10	+	+	+	+	–	–	0.5	0.5
11								
12	+	+	+	+	–	–	+	0.5

movement of phosphorus. Therefore, certain soils may contain a layer of soil material with a high reverting power for phosphorus which may prevent the distribution of phosphorus within the soil irrespective of the soil water movements and the amount of fertilizer applied.

A large amount of rock phosphate was applied to soil No. 4, but the phosphorus tests on soils Nos. 23, 24, 25, and 29, Table 1, also show that water extracts of soils receiving rock phosphate may be as high in content of soluble phosphorus as extracts of soils receiving applications of superphosphates.

Soil No. 5 is an example of a muck soil having a high reverting power for applied phosphorus. The 500 pound plat, after having received seven applications or a total of 3,500 pounds of 16 per cent superphosphate, shows a content of water soluble phosphorus consistent with other plats giving good crop yields, although these amounts may not be sufficient for truck crops. In the case of this soil, the phosphorus is not moving to lower depths. As the 2-inch depth, samples of this soil tested lower than the other samples immediately above and below them; the phosphorus may have moved both upward and downward from this 2-inch depth. Contrasting this soil with soil No. 6, which has received less phosphorus, will emphasize the fact that soils with a high reverting power for phosphorus can not be fertilized as economically as those soils having a low reverting power for phosphorus.

Soil No. 7 is low in water soluble phosphorus, but some of the applied phosphorus remains in a soluble condition and moves freely in it, at least to the depth of ten inches. In the case of the 1,000 and 1,500 pound applications of fertilizer, the manured plats showed somewhat higher phosphorus tests than the unmanured plats.

Higher phosphorus tests were obtained on the check plat of soil No. 8 than on soil No. 7, but 800 pounds of the fertilizer were required to markedly increase the content of water soluble phosphorus on this soil with the increase in favor of the hill applications.

The results shown in the case of soil No. 9 were obtained after two crops had been grown without additional fertilization. These figures strikingly show the residual effects of phosphorus fertilization.

SOIL CONTENT OF WATER SOLUBLE PHOSPHORUS IN FERTILITY EXPERIMENTS ON POTATOES

Method and Object of Study

The method of sampling the soils and of testing the soil samples for water soluble phosphorus was not changed for this part of the work. Cooperative fertility experiments on potatoes with various amounts of phosphorus fertilizers are in progress in the State and these experiments provided the soil locations for carrying on the soil phosphorus studies. The principal object of this study was to determine, if possible, how much water soluble phosphorus a soil should contain in order to produce a good potato crop. The fertilizer formulae used are given as column headings in Table No. 5 and these formulae were made up from the fertilizer materials given under the respective soil type names. Some of the soils received manure in addition to the fertilizer as indicated in the table.

Discussion of Table 5

All of the fertilizer applications, including the 4-0-8 mixture, which contained no phosphorus, increased the soil content of water soluble phosphorus over that of the check plats and the largest applications of phosphorus gave the most water soluble phosphorus and a somewhat greater quantity distribution within the soils. It may be observed from the data presented in Table 5 and also throughout this bulletin, that applications of manure to soils increases the amount of water soluble phosphorus, in some cases quite markedly. As manure contains only a small per cent of phosphorus, in order to produce the results obtained, either the phosphorus of manure must be more soluble in soils than the phosphorus of the other fertilizers used or the manure has produced a dissolving effect on the phosphorus in the soils studied

Table 5.—Depth—Distribution and soil content of soluble phosphorus in fertilized soils growing potatoes. Rate of application of fertilizer, 500 pounds per A., broadcast.

Depth	No. 1. Onaway loam— Sulfate of ammonia 20% superphosphate. Muriate of potash.				No. 2. Mancelona sandy loam— Sulfate of ammonia 20% superphosphate. Muriate of potash.			
	Ck.	4-0-8	4-16-8	4-32-8	Ck.	4-0-8	4-16-8	4-32-8
0	+	0.5	1.0	1.0	+	1.0	2.0	2.0
1		1.0	1.0	1.0		0.5	2.0	2.0
2	+	0.5	0.5	1.0	+	1.0	1.0	1.0
3		+	+	1.0		0.5	0.5	1.0
4	+	+	+	1.0	+	+	0.5	0.5
5		+	+	1.0		+	0.5	0.5
6	+	+	+	1.0	+	0.5	0.5	1.0
7		+	+	1.0		0.5	0.5	1.0
8	+	+	+	1.0	+	+	+	1.0
9								
10	+	+	+	0.5	+	+	+	0.5
11								
12	+	+	+	+	+	+	+	0.5

Depth	No. 3. Rubican loamy sand— Sulfate of ammonia. 20% superphosphate. Muriate of potash.				No. 4. Onaway loam— Sulfate of ammonia. 20% superphosphate. Muriate of potash.			
	Ck.	4-0-8	4-16-8	4-32-8	Ck.	4-0-8	4-16-8	4-32-8
0	+	1.0	2.0	2.0	0.5	0.5	1.0	2.0
1		1.0	1.0	2.0		0.5	1.0	2.0
2	+	1.0	2.0	2.0	+	0.5	0.5	2.0
3		1.0	1.0	1.0		0.5	1.0	1.0
4	+	1.0	0.5	0.5	+	0.5	0.5	1.0
5		1.0	0.5	0.5		0.5	0.5	1.0
6	+	1.0	0.5	0.5	+	0.5	0.5	0.5
7		1.0	0.5	1.0		0.5	0.5	0.5
8	+	0.5	+	0.5	+	0.5	0.5	0.5
9								
10	+	0.5	+	+	+	+	+	+
11								
12	+	0.5	+	0.5	+	+	+	+

Depth	No. 5. Onaway loam— Sheep manure on all plats. Sulfate of ammonia. 20% superphosphate. Muriate of potash.				No. 6. Isabella loam— Sulfate of ammonia. 20% superphosphate. Muriate of potash.			
	Ck.	4-0-8	4-16-8	4-32-8	Ck.	4-0-8	4-16-8	4-32-8
0	0.5	0.5	1.0	2.0	0.5	1.0	2.0	2.0
1		0.5	1.0	2.0		1.0	2.0	3.0
2	0.5	0.5	1.0	1.0	1.0	0.5	1.0	2.0
3		0.5	1.0	1.0		0.5	0.5	1.0
4	0.5	0.5	0.5	0.5		0.5	1.0	3.0
5		0.5	0.5	0.5		0.5	0.5	1.0
6	1.0	0.5	0.5	1.0	0.5	0.5	1.0	1.0
7		0.5	0.5	0.5				
8	0.5	0.5	0.5	0.5		0.5	1.0	1.0
9								
10	1.0	0.5	0.5	0.5	0.5	0.5	2.0	2.0
11								
12	0.5	0.5	0.5	0.5				

Depth	No. 7. Isabella sandy loam— Sulfate of ammonia. 20% superphosphate. Muriate of potash.				No. 8. Same as No. 7, except all plats received 5 loads of manure per A.			
	Ck.	4-0-8	4-16-8	4-32-8	Ck.	4-0-8	4-16-8	4-32-8
0	1.0	0.5	1.0	1.0	0.5	1.0	1.0	2.0
1		+	2.0	1.0		0.5	1.0	2.0
2	0.5	+	1.0	3.0	+	0.5	1.0	3.0
3		+	1.0	2.0		0.5	1.0	2.0
4	+	+	0.5	1.0	+	+	0.5	2.0
5		+	0.5	0.5		+	0.5	2.0
6	+	0.5	0.5	0.5	+	0.5	0.5	2.0
7								
8	+	1.0	0.5	1.0	+	+	+	2.0
9								
10	+	0.5	0.5	0.5	+	0.5	0.5	3.0

Depth	No. 9. Mancelona sandy loam—Sulfate of ammonia. Anaconda phosphate. Muriate of potash.				No. 10. Roselawn loamy sand—Sulfate of ammonia. 20% superphosphate. Muriate of potash.			
	Ck.	4-0-8	4-16-8	4-32-8	Ck.	4-0-8	4-16-8	4-32-8
0	0.5	1.0	1.0	3.0	1.0	2.0	2.0	3.0
1		0.5	1.0	3.0		1.0	3.0	3.0
2	0.5	0.5	1.0	3.0	0.5	2.0	2.0	3.0
3		0.5	0.5	3.0		0.5	3.0	2.0
4	+	0.5	0.5	2.0	0.5	0.5	1.0	3.0
5		0.5	0.5	2.0		0.5	0.5	1.0
6	+	0.5	0.5	1.0	0.5	0.5	0.5	0.5
7		+	0.5	1.0		0.5	0.5	0.5
8	+	+	+	0.5	0.5	1.0	0.5	0.5
9								
10	+	+	+	0.5	+	2.0	1.0	1.0
11								
12	+	+	+	0.5	+	2.0	1.0	0.5

in this investigation. Of special interest is the effect of the 4-0-8 fertilizer mixture on the solubility of soil phosphorus. The sulfate of ammonia and muriate of potash used to make up this 4-0-8 mixture were tested for soluble phosphorus by means of the phosphorus test and no phosphorus was found in them, therefore, the increase in quantity of soluble phosphorus in the plats receiving this fertilizer over the check plats must be due to the dissolving effect of the 4-0-8 mixture on the phosphorus already in the soil.

Discussion of Table 6

In order to arrive at a general conclusion as to the amount of water soluble phosphorus a soil should contain for the potato crop, the average per acre yields were taken for the check plats and the various fertilizer treatments of the 10 separate experiments reported in Table 5; and the phosphorus test results were averaged for a depth of seven inches in each plat leaving the negative (—) tests out of consideration. These data are presented in Table 6 where it can be seen that the highest average potato yield coincides with an average phosphorus test result of approximately 1.0 part per million.

Table 6.—Average potato yields and the seven-inch average phosphorus test results of the ten potato experiments.

Plat treatments	Ck.	4-0-8	4-16-8	4-32-8
Average potato yields—bu	163.1	183.	219.2	21.1
Average phosphorus tests	0.15	0.59	0.96	1.7

SUMMARY

The data presented in this bulletin were obtained by means of a micro-chemical test for water soluble phosphorus in soils. This phosphorus test is described in the first part of the bulletin and some suggestions are given concerning its use. Studies were made on 47 soil locations in order to determine the effects of various kinds and amounts of fertilizers on the water soluble phosphorus of the soils examined. The depth-distribution of soluble phosphorus resulting from depth-placements, broadcast, drilled, and row applications of fertilizers was studied and some of the soil factors influencing this depth-distribution are discussed. Data are presented, also, from 10 soil fertility experiments on potatoes to determine the soil content of water soluble phosphorus necessary for the highest average yield under the conditions of the experiments.

1. Applications of phosphorus fertilizers produced crop increases on all of the soils under observation that showed a content of water soluble phosphorus of 0.5 part per million or less in the soil extracts.
2. Soluble phosphorus moves both upward and downward in soils and these movements are conditioned chiefly by the amount of fertilizer applied, the phosphorus reverting power of the soil, and the freedom of water movements.
3. In the case of soils having a high phosphorus reverting power, broadcasted phosphates may remain where they are mixed with the soil by tillage operations.
4. Row applications of fertilizers gave higher phosphorus tests directly under the row than did broadcast applications.
5. Very large amounts of fertilizers may be required on some soils having a high phosphorus reverting power in order to give an optimum content of water soluble phosphorus for crops.
6. The muck soils which were studied retained nearly all of their soluble phosphorus in the plowed portion, but, in case of the mineral soils, the phosphorus moved to lower depths.
7. Sulfate of ammonia and muriate of potash increase the solubility of soil phosphorus.
8. Either the phosphorus of manure is quite soluble in soils or else manure exerts a solvent action on soil phosphorus.
9. The highest average yield of potatoes from 10 phosphorus experiments correlated with a 7-inch average content of soluble soil phosphorus of approximately 1.0 part per million.

Acknowledgment is due to the several members of the Soils Department staff who laid out the fertility plats, furnished transportation, and gave valuable suggestions for the conductance of these studies.