

T H E S I S

on

AVAILABLE PHOSPHATE TESTS ON CERTAIN OREGON SOIL TYPES

Submitted to the

OREGON STATE AGRICULTURAL COLLEGE

In partial fulfillment of
the requirements for the
Degree of

MASTER OF SCIENCE

by

Earl R. Fogarty

May 12, 1931.

APPROVED:

Redacted for privacy

Professor of Soils
In Charge of Major.

Redacted for privacy

Chairman of Committee on Graduate Study.

ACKNOWLEDGEMENT

The author takes this opportunity to thank Professor C. V. Ruzek and Dr. R. E. Stephenson of the Soil Department of the Oregon State Agricultural College for the many helpful suggestions and courtesies extended to him while he was conducting the studies reported in this manuscript.

OLD BADER BOND
MADE IN U.S.A.

TABLE OF CONTENTS

Introduction - - - - -	5
Purpose- - - - -	6
Historical - - - - -	7
Materials and Methods- - - - -	-15
Methods- - - - -	-19
Results of Investigation - - - - -	-21
Discussion - - - - -	-31
Summary- - - - -	-35

AVAILABLE PHOSPHATE TESTS ON CERTAIN OREGON SOIL TYPES

INTRODUCTION

Most soils contain very limited amounts of phosphorus of which a small part becomes available annually for crop use. The cropping history of arable lands points unmistakably to a phosphorus deficiency often before either nitrogen or organic matter become limiting factors. For this reason phosphorus is frequently referred to as the key to permanent soil fertility and for many years the use of phosphate fertilizers has been a standard practice and has given profitable returns. Field trials on certain types of Oregon soils have shown marked response from the use of soluble phosphorus fertilizers, while on other soils in the same section negative results have been obtained. In most cases the total phosphorus content of both groups of soil is fairly high, which would lead to the assumption that the lack of production in the former and the response to phosphate in these soils is a question of availability. Therefore from a practical standpoint a simple phosphorus test applied to the soil, if it serves as an index to the supply of readily available phosphorus should prove of great economic value and aid materially in furnishing data indicating the probabilities of satisfactory returns from the use

of phosphate fertilizer.

PURPOSE

The determination of the readily available phosphorus of soils is a problem that has been considered by investigators for a long time. A goodly number of these tests for availability have been proposed. The purpose of the work herein reported was to determine whether or not there is a correlation between results obtained by recently developed laboratory tests for available phosphorus and those secured by field trials.

HISTORICAL

The significance of phosphorus as a limiting nutrient in the feeding of plants has been a fact long established. Among the more important questions arising in regard to this nutrient in soils has been that of availability to plants and accurate convenient methods of measuring such availability.

Naturally, phosphorus occurs in the soil as phosphorite or apatite. There are also variable amounts that are in combination with magnesium, aluminum and iron. These phosphates are all practically insoluble in water, that is to say, they are dissolved by pure water so slowly and to such a slight extent that they sustain no appreciable loss in the soil by leaching. In addition to the inorganic combinations, part of the total phosphorus in soils occurs in the organic form (2) (18). Both forms are but slightly soluble and present in minute amounts in the soil solution (15). Pierre and Parker (17) determined the content of organic and inorganic phosphorus in the displaced soil solution and 1 to 5 extract of twenty-one soils from nine states. In the displaced solution they found the average content of inorganic phosphorus to be 0.09 p.p.m. and organic phosphorus 0.43 p.p.m. The 1 to 5 water extracts of the same soils showed an average concentration of 0.35 p.p.m. inorganic phosphorus and 0.22 p.p.m. organic phosphorus. The inorganic was found by Parker (14) to be available while the organic was apparently unavailable.

In comparison with other plant-food elements in the soil solution, the concentration of phosphorus is low. As shown by Burd and Martin (6) the concentration of phosphorus, expressed as PO_4 in the soil solution varies from a trace to 12.5 p.p.m. Teakle (23) at a later date with other soils found that the phosphorus of the soil solution varied from 0.15 p.p.m. PO_4 to about 10 p.p.m.

Usually the total phosphorus supply of soils decreases from the surface downward. This has been pointed out by Alway and Rost (1) working with prairie soils. In some cases however, due to rock decomposition or to movement by water there may be an accumulation at certain depths. Peter (16).

The fact that there is such a small amount of phosphorus in the soil solution has led to the problem of a phosphate deficiency for the nutrition in plants. Much work has been done in this connection and some very valuable information obtained.

It is a well recognized fact that the availability of phosphorus for plant growth is influenced by several factors. The type of plant itself is important and at least in part, differences in the feeding power of plants for phosphorus of comparatively insoluble compounds is due to the amount of CO_2 produced and the contact of roots with the solid phase. Comber (7), Parker (14) Hoagland (12), and Tidmore (24) have all emphasized the importance of this fact in accounting for the absorption of phosphorus from soils especially of the

humid region. Truog (26) says the differences are due to several factors, some of which are concerned with external equilibrium conditions around the feeding roots, and others with permeability of root hairs and equilibrium conditions inside the plant where the elements are actually used. He believes the calcium content of plants explains their common ability to feed strongly on the less soluble phosphates. The extent of the root system of plants is no doubt a very important factor, but not a controlling one.

Climate is without a doubt closely connected with the ability of plants to satisfy their needs for phosphorus. A climate which makes possible a long growing period affects crops so they can get along with a lower supply than those with a shorter growing period, because the longer growing period makes possible the utilization of a greater amount of the less available phosphorus.

Soil reaction has been extensively investigated and found to have a great influence on the availability of phosphorus to plants. Its effect is largely indirect, bringing into solution at certain pH values, other elements which markedly effect the solubility of phosphorus. In acid soils there is present in the soil hydrated oxides of iron and aluminum. As the soil becomes more acid, increasing amounts of iron and aluminum are found in soluble form in the soil solution. Freshly pre-

precipitated iron and aluminum phosphates are available sources of this element for plants, while the finely ground, naturally occurring phosphates, and more basic residues of these metals are almost wholly unavailable. This phenomena has been explained by Brezeale and Burgess (5), Magistadt (13) Truog, (25) Teakle (22) and others by pointing out that freshly precipitated iron or aluminum phosphate invariably contains an excess of phosphate ions over that required to form the $FePO_4$ or $AlPO_4$. It is thus acidic rather than basic, and hence much more soluble and available. When aqueous solutions come in contact with these phosphates, the phosphate ion is removed more rapidly than is the Fe or Al ion, resulting in a more basic residue, which is more insoluble. As this action progresses and the degree of hydrolysis increases the phosphates become increasingly insoluble.

This explanation also holds true in the case of calcium phosphate in alkaline solutions. Although as has been shown by Black (3) in working on alkali soils of Oregon, there are large amounts of soluble phosphate in these soils when its reaction is above pH 8. The sodium ion concentrations and the calcium ion concentrations appear to be the most important factors in the phosphate solubility of these soils. Sodium ions increase and excess Ca ions decrease phosphate solubility in these soil extracts.

Other workers have reported similar solubility effects

on $\text{Ca}_3(\text{PO}_4)_2$ on the alkaline side. Teakle (22) shows that unless an excess of calcium ions is maintained in the solution $\text{Ca}_3(\text{PO}_4)_2$ becomes soluble at alkaline reactions. Fisher (10) at Rothamstead reports that Na_2SiO_3 makes phosphate available. Spurway, Greaves and others as reported by Black (3) working on alkaline soils have shown that phosphate could be expected to become more soluble in alkaline reactions.

The presence of organic matter in soils has some influence on the availability of phosphorus. It has been suggested that the organic acids formed in the decomposition of organic matter have a solvent action on the less soluble phosphates in the soil. In recent work by Stephenson and Chapman (21) on California soils it was indicated that the phosphorus in manure moves readily through the soil or some action of organic matter facilitates the more rapid penetration of phosphorus. Pierre and Parker (17) have found that most of the phosphorus in the displaced solutions is in the organic form and the concentration of inorganic phosphate in such solutions is very low. The water soluble organic phosphates according to their work is not absorbed by plants and is consequently unavailable to the plant as long as it remains in the organic form.

The insolubility of organic phosphate does not mean that such phosphates may not become available to the plant by biological agencies within the soil. It is probable in all soils,

organic phosphates are being decomposed by bacterial action and the phosphorus made available to the plant. The time necessary for phosphorus to become available from organic phosphates depends on a number of factors, the most important probably being the nature of the organic matter.

Due to such small amounts of phosphorus in the soil solution and the complexity of the problem of the availability of this element to plants, there has been a real need for a rapid, accurate and sensitive method for its determination.

Recent developments in devising such a method for use in the field or laboratory have included much work and several papers have appeared in the last few years. The methods are all colorimetric and depend on the production of a blue color when phosphomolybdic acid is reduced with stannous chloride under suitable conditions.

The original method for determining phosphoric acid in water solutions was developed in 1920 by Deniges (8), a French investigator. He used a 10 per cent ammonium molybdate solution to which was added an equal volume of strong sulphuric acid, and as a reducing solution, 0.1 g. of tin, in the form of foil, dissolved in 2 c. c. of hydrochloric acid with the aid of a drop of 4 per cent copper sulphate, and then made up to 10 c. c. This solution keeps for only twenty-four hours.

This method has been used by Parker and Fudge (15) and many other investigators, and improvements have been made

applicable to the conditions under which they were working.

Later in 1928, in a second paper Deniges (9) applied his method to the case of water and acid extracts of soils.

This method has been perfected by Truog and Meyer (27) and is undoubtedly one of the most satisfactory colorimetric determinations in existence. In comparison to the old method, the amount of ammonium molybdate is doubled and acidity is increased. With these amounts and proportions of reagents the method is made considerably more sensitive, especially to small amounts of phosphate because the full effect of all the phosphate is probably brought into play. Evidence that this is the case is furnished by the fact that the full color develops immediately on addition of the stannous chloride.

Effects from even high amounts of silica are entirely eliminated with the concentration of the reagents used. In the case of stannous chloride, the solution is made up and prepared by covering with a layer of white mineral oil to prevent oxidation. This is a distinct advantage over the Deniges method, where the solution has to be made fresh daily.

Spurway (20) with some modification has developed the test for field use. He uses a solution of 2 per cent ammonium molybdate in nitric acid, and mixes one part of strong acid with three parts of water, effecting the phosphomolybdate reduction by stirring with a tin rod.

For tests on smaller samples, Bray (4) uses a solution of 0.4 per cent ammonium molybdate dissolved in hydrochloric acid made up by mixing one part of strong acid with forty of water. The soil is shaken with three parts of the molybdate solution in a test tube, allowed to stand for five minutes and then stirred with a tin rod. A color chart is used for matching colors in both Bray and Spurway's test.

Recently Truog (28) has proposed a method for the extraction of the readily available phosphorus of soils. He goes on the theory that it is practical to use a solvent which is approximately the same strength as the one from which the plants obtain their food. There is evidence which indicates that the solvent at the point of contact between root hairs and soil particles is a saturated solution of carbonic acid, having a normality of $1/25$ and a pH of 3.7. Truog (28) therefore proposes the use of a .002 N solution of sulfuric acid, buffered with ammonium sulfate to a pH of 3.0. This is used in the proportion of 200 c. c. of solvent to 1 of soil to extract the readily available phosphorus in the soil.

This method has been used quite extensively and seems to give quite satisfactory results.

MATERIALS AND METHODS

Soils Studied

The soils studied were from three distinct areas in the state representing humid, arid and semi-arid sections. These are the Willamette Valley with an annual rainfall of approximately 45 inches, the Rogue River Valley with a rainfall of about 20 inches and the Snake River Basin with a rainfall of nearly 8 inches. The conditions under which each group of soils were formed varied widely and there is a marked difference in both their limestone requirement and hydrogen ion concentration.

Willamette Valley Soils.

Most of the analysis made were on the Willamette clay loam soil type taken from the plots of a field fertilizer experiment on the college experiment station farm. This soil has been formed under relatively high rainfall. It is classified as an old valley filling soil, brown in color with a friable structure. The subsoil is lighter in color and slightly more compact. The type represents a large area in western Oregon and occupies the gently sloping valley terraces. It is well drained and above average in crop producing power.

Previous to beginning the fertilizer experiment in 1923, general farming was practiced on this field alternating small

grains with vetch and oats and vetch for hay. The two previous years heavy applications of barnyard manure were made and the soil was in a good state of production. At the beginning of the fertilizer experiment, a three year rotation was established and all plots were treated with fertilizer materials. The rotation is fall wheat, red clover and corn. There are three ranges of plots so each crop is being grown every year. The clover is seeded on the fall sown wheat in the latter part of February, the grain serving as a nurse crop. If the clover fails, vetch and oats are seeded the fall after the wheat harvest. Since the establishment of the rotation all subsequent applications of fertilizer have been made after plowing and previous to seeding the corn crop. Field trials on this soil show no marked increase from the use of phosphate. The laboratory tests were carried on primarily to obtain data relative to the probable penetration of phosphates into the lower soil horizons.

Two other soil types from the Willamette Valley area were used; the Cove clay and Aiken silty clay loam. Under field condition both types respond to the application of soluble phosphate fertilizers. The soils of the Aiken series are extensive in area in the Pacific Coast section. They are residual in origin and have been formed by the decomposition of basalt under relatively high rainfall conditions. This has resulted

in heavy textured types, red in color with a high iron content and distinctly acid in reaction. Locally these soils are known as the red hill soils and occupy the upper slopes and crests of hills.

The Cove clay is an extremely heavy soil occurring on the first benches along streams and is of recent alluvial origin. It is black in color and high in organic matter but is not friable nor easy to develop good tilth due to its high clay content. Under certain conditions in field trials, soluble phosphates have given increases in yields.

Rogue River Valley Soils.

The soils from the Rogue River Valley section used for analysis represent a group that were formed under conditions that are intermediate compared with the highly acid soils of the heavy rainfall sections and the alkali soils of the low rainfall or arid sections east of the Cascade Range. Four soil types were used, the Medford gravelly clay loam and the clay adobe, and the Meyer silty clay loam and the clay adobe. The soils of the Medford series range in texture from gravelly fine sandy loam to clay adobe. The soils and subsoils are of dark color, are derived from a variety of rocks, and consist mainly of alluvial deposits of minor intermittent streams. The surface is usually gently sloping or flat and in mode of origin and topographic position they do not differ materially

from the recent soils of the river flood plains and terraces. Some of the types carry subangular gravel to quite an extent.

The soils from the Meyer series are derived mainly from material washed from basaltic rocks, but include some material from shale and sandstone. The subsoils are in part residual from shale and sandstones, which usually lie at shallow depths. Some of the soils have surface material that is of residual origin. These soils occupy lower mountain slopes and hilly rolling land. The slope is moderate to steep, outcrops of shale and sandstone are common, and small quantities of water worn gravel are included in the soil. The depth of the soils is extremely variable, and this, together with the often abrupt slopes, renders portions of this series non-agricultural.

The soils of the Rogue River Valley are important in the production of superior quality of pears.

Evidence from field trials conducted on these soils points to little response from the use of phosphate fertilizers.

Snake River Basin.

The soils from the Snake River section are from an alkali experiment field in the upper Malheur Valley. They are alluvial in formation and occupy the bench lands that run parallel to the streams. These soils have been under irrigation and due to improper internal drainage and to seepage from higher benches a distinct alkali condition has developed. They are characterized by a high salt content, high alkaline reaction and poor

structure resulting in impermeability to water.

METHODS

Methods of Sampling the Soil.

Composite samples of the 0-8 inch, 8-16 inch and 16-36 inch horizons were used for tests on the Willamette clay loam soil. The samples from the Rogue River Valley area were in six inch horizons to a depth of thirty-six inches and those from the Snake River basin were from the surface soil and a second food sample. The other soils used were surface samples to a depth of eight inches.

All soil samples were air dried, run through a 20 mesh sieve and stored in containers until needed for analysis.

Chemical Methods.

The following chemical analysis were made on all soil samples. (1) hydrogen ion concentration, (2) limestone requirement, (3) colorimetric phosphate determination of acid extracts, (4) and of water extracts and (5) the Illinois field method for soluble phosphates.

The pH determination of the soils were made colorimetrically and the limestone requirement by the Truog method.

The phosphate determinations were made by the Truog (28) modification of the Deniges method as follows.

Acid soluble:- Two grams of air dried 20 mesh soil were treated with 400 cc of .002 N H_2SO_4 , buffered with ammonium

sulfate to a pH of 3.0, and shaken continuously for 30 minutes. Then they were filtered through phosphorus free filter paper. To 50 c. c. of clear filtrate, 2 c. c. of ammonium molybdate-sulfuric acid solution and three drops of stannous chloride solution was added. The mixture is shaken well and compared with the standard within a few minutes. The readings were obtained through the use of a colorimeter.

Water soluble:- A 1 to 5 soils water suspension was shaken one hour, 1 gram of sodium chloride was added in order to flocculate the soil to an extent that a clear filtrate could be obtained by the use of phosphorus free filter paper and an ordinary glass funnel. Phosphate was determined in the extract by Truog's modification of the Deniges colorimetric method as outlined above.

Illinois method:- A testing solution consisting of approximately 0.72 N hydrochloric acid and 0.36 per cent of ammonium molybdate was added to the soil in the proportion of one part of soil to three parts of the solution. The mixture was shaken and the soil allowed to settle. The supernatant solution was stirred with a tin rod which resulted in the reduction of any phosphomolybdate present. The interpretation of the depth of color obtained was a comparison with the color chart in Bulletin No. 337, of the Illinois Agricultural Experiment Station.

RESULTS OF INVESTIGATIONS

The data in Table I show the phosphate and pH determinations with crop yields on the fertilized plots representing Willamette clay loam. The fertilizer treatments were applied before any crops were seeded and again before each corn crop in the three year rotation system.

The crop yields are available for each plot, and complete each year back to 1923, which was the time the experiments were started. Averages for the eight year period are reported.

From a study of the analytical data, it is apparent that in the majority of cases the soluble phosphate is greater in the surface soil and gradually decreases as depth of sample increases. This fact is well supported in both acid and water soluble phosphate determinations. This is probably due to the fact that all plots received a heavy application of manure previous to the time they were developed for investigational use.

Results from the Illinois HCl soluble method do not check with those obtained with dilute sulfuric acid and water soluble methods.

The hydrogen ion concentrations approach neutrality and remain fairly constant for the different plots studied, regardless of the depth the sample was taken. The lime requirement shows a greater variation, decreasing in cases where limestone was added in combination with the phosphate carriers,

and increasing where it was omitted, especially in the case of combination of sulfur with the phosphate fertilizers.

The crop yields represent an average of an eight year period and in most cases correlate with amount of phosphorus found in the soil.

TABLE I
Phosphate and Acidity Determinations with Crop Yields on
Experimental Plots on Willamette Clay Loam

No.	Soil Treatment	Depth : Inches	Phosphates			Illinois : HCl : Soluble	pH	Acidity	Yields*		
			H ₂ SO ₄ : p.p.m. : of P.	Water : p.p.m. : of P.	Truog : pH				Hay : Tons	Corn : Tons	Wheat : Bu.
1	Check	0-8	110.0	.35	Medium	6.3	Medium				
		8-16	105.0	.25	Medium	6.5	Very slight				
		16-36	50.0	.00	Low to Doubtful	6.7	Strong	4.66	7.54	56.1	
2	Check	0-8	110.0	.95	Medium	6.9	Medium				
		8-16	100.0	.50	Medium +	6.7	Medium				
		16-36	95.0	.00	Medium -	7.1	Medium -	4.83	8.81	45.7	
3	Check	0-8	110.0	.30	Medium	6.7	Strong -				
		8-16	90.0	.00	High -	7.3	Slight				
		16-36	102.5	.00	High +	7.1	Medium +	3.61	5.68	42.9	
4	2 Ton Limestone	0-8	137.5	.37	Medium	7.1	Very slight				
		8-16	115.0	.20	High +	6.7	Medium				
		16-36	75.0	.00	Medium to Doubtful	6.9	Slight	4.66	7.66	51.4	
5	2 Ton Limestone 15 Ton Manure	0-8	107.5	.50	High	6.7	Slight				
		8-16	100.0	.00	Medium	7.1	Slight				
		16-36	80.0	.00	High	6.7	Slight +	4.88	7.99	51.4	
6	2 Ton Limestone 15 Ton Manure 250# super phosphate	0-8	132.5	.75	High -	6.7	Slight +				
		8-16	87.5	.00	Medium	6.9	Medium -				
		16-36	70.0	.00	Medium	6.9	Slight	4.58	8.09	48.9	

TABLE I Continued

No.	Soil Treatment	Depth : Inches	Phosphates			HCl Soluble	pH	Acidity	Yields*		
			H ₂ SO ₄ :p.p.m. : of P.	Water :p.p.m. : of P.	Illinois : HCl : Soluble				Hay : Tons	Corn : Tons	Wheat : Bu.
7.	2 Ton Limestone	0-8	145.0	.93	High	6.5	Slight +				
	15 Ton Manure	8-16	125.0	.33	Doubtful	6.7	Strong -				
	600# Rock Phosphate	16-36	100.0	.00	Medium	6.9	Slight +	4.86	8.19	54.3	
8.	100# Treble Phosphate	0-8	135.0	.55	High	6.9	Strong-				
		8-16	130.0	.25	High	6.9	Strong				
		16-36	112.5	.00	Medium	7.1	Slight +	4.81	7.59	48.7	
9.	600# Rock Phosphate 100# Sulfur	0-8	140.0	.68	High	6.7	Strong +				
		8-16	132.5	.33	High	6.9	Strong				
		16-36	92.5	.00	High	6.6	Strong +	4.23	7.01	46.0	
10.	250# Superphosphate	0-8	130.0	.63	Medium	7.1	Strong				
		8-16	102.5	.45	High	7.1	Strong				
		16-36	97.5	.00	High	6.9	Slight	4.93	8.75	49.4	
11.	600# Rock Phosphate 15 Ton Manure 100# Sulfur	0-8	125.0	.68	High -	6.7	Strong +				
		8-16	115.0	.25	High	7.0	Strong +				
		16-36	95.0	.00	High	7.0	Medium -	4.00	6.98	46.5	
12.	250# Superphosphate 15 Ton Manure	0-8	120.0	.53	High +	6.7	Strong +				
		8-16	112.5	.28	High +	6.7	Strong				
		16-36	80.0	.00	High	7.1	Slight +	4.42	6.90	46.2	
13.	250# Superphosphate Crop Residue	0-8	115.0	.43	Medium +	6.7	Strong				
		8-16	110.0	.00	High	7.0	Medium -				
		16-36	100.0	.20	High +	6.7	Medium +	4.31	6.40	42.4	

* Average for 8 years

Table II shows the results of phosphate and pH determinations on soils from the Rogue River Valley area which is representative of the semi-arid section.

From the data presented it is quite apparent that these soils are low in amounts of soluble phosphate. Phosphates are deficient to such an extent that the water extract does not give enough to draw any conclusions.

The acid soluble shows amounts present to an extent that some conclusions can be drawn. In these soils as was true of those in the Willamette Valley section there is a larger amount of phosphorus in the surface soil than in respective depths below.

The Illinois HCl soluble method shows amounts of phosphorus, that compare somewhat with the results of the .002 N sulfuric acid method.

The pH determinations indicate in most cases a slightly alkaline reaction in these soils, indicating there is not a deficiency in lime.

In sampling these soils no data could be obtained as to whether fertilizers in any form had been applied, so the vigor of plant growth was taken as an index of the fertility of the soil. The results obtained seem to indicate that in these soils phosphorus was not a limiting factor in the vigor of plant growth.

TABLE II
Phosphate and Acidity Determinations on Soils of Rogue River Valley

No.	Soil Type	Phosphates				
		Depth in Inches	.002 N H ₂ SO ₄ Soluble p.p.m. of P.	Water Soluble p.p.m. of P.	Illinois HCl Soluble	pH
14	Medford Gravelly Clay Loam	0-6	43.13	.55	High -	7.3
		6-12	48.15	.125	Medium +	7.1
		12-24	67.25	.00	Medium +	7.6
		24-36	13.63	.00	Medium +	7.8
15	Medford Gravelly Clay Loam	0-6	103.5	1.175	Medium	7.3
		6-12	95.06	.125	Medium	7.5
		12-24	87.99	.00	Medium -	7.7
		24-36	36.22	.00	Medium -	7.8
16	Meyer Clay Adobe	0-6	82.77	.275	Doubtful	7.3
		6-12	93.14	.00	Medium -	7.1
		12-24	95.06	.125	Medium	7.0
		24-36	106.08	.175	Medium	7.1
17	Meyer Silty Clay Loam	0-6	55.19	.238	Medium -	6.9
		6-12	37.95	.125	Medium	6.9
		12-24	43.13	.00	Medium	6.9
		24-36	23.28	.00	Medium -	7.1
18	Medford Clay Adobe	0-6	29.67	.00	Medium -	7.3
		6-12	28.04	.00	Medium -	7.4
		12-24	28.04	.00	Medium +	7.6
		24-36	24.78	.00	High -	7.8

In Table III results of phosphate and pH determinations on the Snake River Basin are given. These soils are typical of the black alkali soils of eastern Oregon, having large amounts of sodium carbonate present.

The amount of soluble phosphorus present is large. The acid extracts brings such large amounts of phosphorus into solution that conclusions may be obscure. The water extracts in this case give a better measure of phosphorus distribution. It indicates the presence of phosphorus in larger amounts in the subsoil than in the surface. This may be accounted for by the fact that leaching experiments conducted on these plots have transported the soluble phosphorus to lower horizons and possibly a great deal has been leached away. The application of manure in the case of one of these plots results in an increase of soluble phosphorus.

The Illinois HCl soluble method shows a very high concentration of soluble phosphorus which checks with both the .002 N H₂SO₄ soluble and the water soluble methods.

The pH values of the soils are fairly constant except in the case of large applications of sulfur where a reduction of alkalinity has resulted in the subsoil.

TABLE III
Phosphate and Acidity Determinations on Soils of the Snake River Basin

No.	Soil	Depth :Inches:	p.p.m. of P.	Phosphates		
				:.002 N H ₂ SO ₄ : Soluble	Water Soluble Illinois :p.p.m. of P.:	HCl Soluble: pH
19	Vale-check	0-4	350	6.0	Very High	9.4
		4-24	370	5.5	" "	9.4
20	Vale-3000# Sulfur	0-4	320	8.75	Very High	9.5
		4-24	360	11.50	" "	8.6
21	Vale-Total Manure 40T	0-4	400	8.5	Very High	9.5
		4-24	610	13.0	" "	9.5
22	Ritzville Loam	0-8	145	2.5	Very High	8.6

Table IV gives the different phosphate tests on various soil types and the response of these soils to field applications of soluble phosphate fertilizers. There is a distinct correlation between the .002N sulfuric acid extract results and those of field trials.

The water soluble extracts give amounts too small for definite interpretation. The Illinois method gives results that are positive but do not apply as well in doubtful cases.

TABLE IV
Phosphate Tests vs Crop Response to Phosphate Application

Soil	Depth in Inches	Phosphates			pH	Response to Phosphate Fertilizers
		:CO ₂ N H ₂ SO ₄ Soluble p.p.m. of P.:	:Water Soluble: p.p.m. of P.:	: Illinois HCl Soluble:		
Willamette Clay Loam	0-8	110.0	.50	Medium	6.6	Negative
Cove Clay	0-8	21.0	.00	Med. to Doubtful	7.1	Positive
Aiken Silty Clay Loam	0-8	22.0	.00	Med. to Doubtful	6.5	Positive
Dayton Silty Clay Loam	0-8	125.0	3.0	-----	---	Negative
Medford	0-8	58.8	.58	Medium -	7.3	Doubtful
Meyer	0-8	69.0	.25	Medium -	7.1	Doubtful
Ritzville Loam	0-8	145.0	2.5	Very High	8.6	Negative
Vale	0-4	250.0	6.0	Very High	9.4	Negative

DISCUSSION

A study of the phosphate concentration of fertilized plots on Willamette clay loam, strongly indicates that there is a decrease in the amount of soluble phosphorus from the surface soil downward. This indicates that there is little or no movement of soluble phosphorus in soils from regions of high concentrations to those of lower concentrations. It is evident therefore that in the application of phosphate fertilizers on heavy soils it is practical to place the fertilizer in the region of the feeding zone of the plant. Possibly it is of greater advantage to do this because of the concentrations of the phosphorus in larger amounts in one area, thus satisfying the absorption power of the soil, and leaving soluble phosphorus in excess for use by the plants; whereas in applying the fertilizer broadcast, the relative concentration per unit area is smaller, it is absorbed by the soil, and becomes unavailable to the plant. Stephenson and Chapman (21) working on the penetrations of phosphate in soils found little or no penetrations in heavy soils, but quite an appreciable amount below the surface foot in those of medium or light texture.

The untreated plots showed quite high amounts of soluble phosphorus which is probably due to heavy applications of manure before this area was set aside for investigational purposes. The phosphorus in manure or else some effect of

organic matter on the solubility of phosphorus already in the soil has increased the supply in these plots. In every case where phosphate fertilizer was applied there is an increase of soluble phosphate in the first eight inches of soil over that of the check, but only in the case of treble phosphate, and superphosphate with manure was there any increase in soluble phosphates at lower depths.

Where the water soluble method of extraction is used on soils neutral or nearly neutral in reaction the phosphate obtained is in such small amounts as to be insignificant for conclusions. Under such conditions it seems advisable to use the acid method of extracting in order to get enough phosphorus for comparison of results. On the other hand in soils having a pH value greater than that near neutrality, or in light textured soils which in both cases results in more phosphorus being in solution, the water soluble method of extraction is superior to the acid soluble. In case of the latter so much phosphorus is brought into solution that there is a tendency for the obscurity of results. Stephenson and Chapman (21) pointed out quite decidedly that with most of the soils with which they worked the water soluble method of extraction was better adapted to show phosphate movement than the acid extract. Small quantities of phosphates moving into deeper soil horizons could be detected in the water extracts, whereas in the case of acid extracts so much phosphate was brought into solution

that differences could not be readily detected.

The hydrogen ion concentration of the soils studied varies from a minimum of pH 6.3 in soils of the Willamette valley to a maximum of pH 9.5 in soils of the Snake River basin of eastern Oregon. As the pH tends towards acidity there is less soluble phosphate in the soil. According to Brezeale and Burgess, (5) Magistadt (13) and Truog (25) in acid reactions Fe and Al come into solution, combining with the phosphates to form insoluble Fe and Al phosphates. When these compounds are freshly precipitated they are a source of some soluble phosphorus for plants, but as the phosphate ion is removed from the molecule Fe and Al hydrates are formed and the phosphorus becomes increasingly insoluble.

As the pH becomes increasingly higher there is a corresponding increase in both water soluble and acid soluble phosphates. This is in accord with the finding of other investigators. Black (3) working with soils from the Vale section found large amounts of phosphate soluble where the soil reaction was above pH 8. Other workers, Teakle (22), Fisher (10) and Spurway (19) have reported similar solubility effects on phosphates in alkaline reactions. The sodium ion concentration in alkaline soils is an important factor in the solubility of phosphates. Sodium ions increase phosphate solubility in alkaline soils and an excess of calcium ions cause a decrease. Greaves (11) found that treatment with sodium carbonate caused phosphate to

leach from the soil, so those soils high in sodium carbonate present a problem of loss of phosphates from leaching.

In comparing results obtained by the Illinois HCl method of determination with those of the .002 N sulfuric acid and water soluble methods, correlation is secured only in cases where soluble phosphorus is present in the soil in very large amounts or where there are extremely small amounts. In case of the fertilized plots where there was a medium amount of soluble phosphorus present, no correlation existed between the Illinois field trial method and the dilute sulfuric acid method. It therefore seems possible that such a test can be used only as a qualitative measure where information is desired as to the accumulation of phosphorus in soils, even though it cannot be used as a reliable quantitative measurement.

Crop yields in most cases seemed to correlate with the amount of soluble phosphorus in the soil.

SUMMARY

1. Water soluble extracts on soils neutral or nearly neutral in reaction do not give amounts of phosphate sufficient for conclusion.
2. There is decrease in the amount of soluble phosphate with depth.
3. Crop yields and amounts of soluble phosphate correlate.
4. As the pH tends towards alkalinity both water soluble and acid soluble phosphate increase.
5. Increase in lime requirement tends towards less soluble phosphate.
6. The Illinois HCl soluble method checks with the .002 N sulfuric acid and water soluble methods only in the case of very high and very low concentrations of soluble phosphate.

LITERATURE CITED

1. Alway, F. T., and Rost, C. O.
1916 The vertical distribution of phosphorus in
the surface soils of prairies.
Soil Sci. 2: 493-497.
2. Auten, J. T.
1923 Organic phosphorus of soils.
Soil Sci. 16: 281-294.
3. Black, W. V.
1929 The removal of soluble salts from virgin
"Black Alkali" soil.
Thesis submitted to Ore. State Agr. College:
1-72.
4. Bray, R. H.
1929 A field test for available phosphorus in soils.
Ill. Agric. Exp. Sta. Bul. 337: 591-602.
5. Brezeale, J. F., and Burgess, P. S.
1926 The availability of phosphates in calcareous
or alkaline soils.
Uni. Ariz. Tech. Bul. 10: 209-237.
6. Burd, J. S., and Martin, J. C.
1923 Water displacement of soils and the soil solution.
Jour. Agric. Sci. 13: 265-295.
7. Comber, N. M.
1922 The availability of mineral plant food.
Jour. Agric. Sci. 12: 365-369.
8. Deniges, G.
1920 Comptes Rendus
Vol. 171: 802-804.
9. Deniges, G.
1928 Comptes Rendus
Vol. 186: 1052-4.
10. Fisher, R. A.
1929 A preliminary note on the effect of sodium
silicate in increasing the yield of barley.
Jour. Agric. Sci. Vol. 19: 132-133.

11. Greaves, J. E., Hirst, E. T., and Yeppa Lund
1923 The leaching of alkali soil.
Soil Sci. Vol. 16: 407-426.
12. Hoagland, D. R., and Martin, J. C.
1927 Recent experiments concerning the adequacy of artificial culture solutions and of soil solutions for the growth of different types of plants.
Proc. and Papers First Internat'l. Cong. Soil Sci. 3: 381-392.
13. Magistadt, O. C.
1925 The aluminum content of the soil solution and its relation to soil reaction and plant growth.
Soil Sci. 20: 181-213.
14. Parker, F. W.
1927 Plant growth and the absorption of phosphorus from culture solutions of different phosphate concentration.
Soil Sci. 24: 129-146.
15. Parker, F. W., and Fudge, J. F.
1927 The colorimetric determination of organic and inorganic phosphorus in soil extracts and the soil solution.
Soil Sci. 24: 109-117.
16. Peter, A. M.
1916 On the distribution of phosphorus in a vertical section of bluegrass soil.
Soil Sci. 2: 387-393.
17. Pierre, W. H., and Parker, F. W.
1927 The concentration of organic and inorganic phosphorus in the soil solution and soil extracts and the availability of the organic phosphorus to plants.
Soil Sci. 24: 119-128.
18. Schreiner, Q.
1924 Organic phosphorus in soils.
Jour. Amer. Soc. Agron. 15: 117-124.
19. Spurway, C. H.
1925 Some factors influencing the solubility of phosphorous in soil and phosphate mixtures.
Soil Sci. Vol. 19: 399-405.

20. Spurway, C. H.
1929 A test for water soluble phosphorus.
Mich. Agric. Exp. Sta. Bul. 101: 1-25.
21. Stephenson, R. E., and Chapman, H. D.
1931 Phosphate penetration in field soil.
Unpublished data.
22. Teakle, L. J. H.
1928 Phosphate in the soil solution as affected
by reaction and cation concentrations.
Soil Sci. 25: 143.
23. Teakle, L. J. H.
1929 The absorption of phosphate from soil and
solution cultures.
Plant Phys. 4: 213-232.
24. Tidmore, J. W.
1930 Phosphate studies in solution cultures.
Soil Sci. 30: 13-31.
25. Truog, E.
1916 The utilization of phosphates by agricultural
crops, including a new theory regarding the
feeding power of plants.
Uni. Wis. Res. Bul. 41: 1-50.
26. Truog, E.
1927 How plants feed.
Proc. and Papers First Internat'l. Cong.
Soil Sci. 3: 628-636.
27. Truog, E., and Meyer, A. H.
1929 Improvements in the Deniges colorimetric
method for phosphorus and arsenic.
Ind. and Eng. Chem., Anal. Ed. 1: 136-139.
28. Truog, E.
1930 The determination of the readily available
phosphorus of soils.
Jour. Amer. Soc. Agron. 22: 874-882.