PHOSPHORUS REQUIREMENT OF RED HILL SOILS AS SHOWN BY GREENHOUSE AND CHEMICAL TESTS

by

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PHOSPHORUS REQUIREMENT OF RED HILL SOILS AS SHOWN BY GREENHOUSE AND CHEMICAL TESTS

INTRODUCTION

The "red hill" soils of Western Oregon are frequently low in available phosphorus, and marked by their high capacity to fix soluble phosphorus. These soils give a definite crop response to applications of soluble phosphate fertilizers. The problem of the availability of phosphorus to plants growing on these soils is of special importance, particularly so in the production of field crops. It was the purpose of this study to obtain an estimate of the amount of soluble phosphorus needed for increased crop production on these soils as determined by chemical and greenhouse tests.

In most soils the phosphorus problem is threefold: (1) the small total amount of phosphorus in the soil; (2) the unavailability of this soil phosphorus; (3) a marked fixation of soluble phosphates. In the soils used in this study the latter two factors predominate.

HISTORICAL REVIEW

Phosphorus Requirement of the Soil. With the exception of nitrogen no single nutrient is more important in general farming than that of phosphorus. Low crop yields are frequently due to a lack of this nutrient in an available form. This lack of available phosphorus in the soil may be attributed to: (1) a low initial phosphorus content of the soil, (2) the fact that phosphorus is tied up in organic matter and in insoluble inorganic compounds, and (3) the fact that phosphorus is removed from the soil in rather large amounts by that portion of the crop which is sold from the farm.

When a soil contains adequate amounts of available phosphorus to produce maximum yields under a given set of climatic and soil conditions, the soil is then said to possess sufficient phosphorus. Since varying amounts of the phosphorus which is applied are "fixed" in the soil, the problem of determining the amount to apply to deficient soils to obtain increases in yield has become increasingly important.

Noting the character of native vegetation according to Weir (30,p.536) is the oldest means of judging the potential productiveness of the soil. This method of characterizing agricultural land still has value today. Weir (30, p.537) points out that the next method used was that of analysis of plant ash, but that it cannot be relied upon to indicate the need for fertilizers. Following this conception was that of Sir Humphry Davy (England) with the idea that there is a relationship between total chemical composition of soils and soil fertility. While there is some value to a total chemical analysis in revealing the chemical nature of the soils, Weir points out that while Liebig at first valued this method highly, later he was among the first to recognize that it seldom gave a correct standard for measuring the fertility of soils.

Our earliest records of growing plants in plots, according to Bear (2, p.IX), go back to the time of Johan Baptista van Helmont (1620). This is in agreement with Weir (30, p.541) who points out that Home (1755-1757) performed the earliest modern scientific work pertaining to plant nutrition.

Pot tests, according to Weir (30, p.543), are regarded as ranking second to field tests for reliability. Cox (6, p.97), shows that for the most accurate experimentation under greenhouse conditions, a knowledge of the variation due to structure and location of the greenhouse, and of the variability of the seed used is of prime importance.

Dyer (1894), according to Bear (2, p.XIII), conducted the first availability studies on soils. He used a one percent citric acid solution as a means of measuring the availability of soil phosphorus. It was his studies on the acidity of plant sap that led him to select a one percent citric acid solution. Subsequent investigators worked with weak solutions of oxalic, tartaric, aspartic, acetic, and nitric acids.

According to Collings (5, p.429), the most popular methods now used for determining the fertilizer needs of soils are the recently developed rapid chemical soil tests. When these tests are standardized against field results and properly interpreted, they have a diagnostic value. Reliability for all crops on all types of soils cannot be claimed for any single test. This is in agreement with the view put forth by Smith (23, p.452), who points out that no satisfactory method has been devised to indicate the amount of phosphorus in an available form in a soil.

The present chemical methods for evaluating the available phosphorus content of soils are emperical. They involve the use of widely different types of extracting solutions. Distilled water is being used by Martin (4, pp.2-4) in testing California grain land for available phosphorus. Apparently good results have been obtained on both acid and alkaline soils. Smith (24, pp.1-9) has recommended the use of CO_2 in water for the calcareous soil of Idaho. Results up to the present time have been satisfactory. Of the methods employing dilute acids, the procedure proposed by Truog (27, pp.879-881) using .002N H_2SO_4 has been widely used in this country. According to Collings (5, p.430) this method was one of the three most popular methods used in the United States in 1936. Inorganic acids, HNO_3, HCl, and H_2SO_4, in equivalent concentration, according to Hibbard (9, pp.462-464), dissolve approximately the same amounts of phosphorus from soils. In recent years highly buffered acidic salt solutions such as the sodium acetate solutions used by Pennsylvania (16, pp.2-3), and by the Connecticut Agricultural Experiment Station (14, pp.14-15) have been used. As pointed out by Peech (2, pp.36-37), the main advantage of such highly buffered solutions over the dilute inorganic acids is that their solvent action remains relatively unchanged even upon prolonged contact with soil containing moderate amounts of calcium carbonate.

It has been demonstrated according to Graham (7, p.6) and Jenny (10, pp.23-24)(11, pp.271-272), that the exchangeable ions adsorbed on the surface of colloidal particles are readily available to plants. A method which is in common use now is that proposed by Bray (3 p.42). Ammonium fluoride .03N in an .025 hydrochloric acid solution is used to measure the adsorbed or exchangeable phosphorus in soils. This method as stated by Bray (4, pp.83-84) meets all of the requirements for a successful soil test.

The Need for Phosphorus on "Red Hill" Soils. Studies by Ruzek (20, pp.4,13)(21, pp.4,6) and Powers (18, pp.15, 19) showed that these soils responded to phosphorus fertilization on field crops. Wheeting (31, pp.42-47) carried on fertilizer trials in the field with several crops on several soils including the Olympic and Melbourne series. He reported response from the use of nitrogen, phosphorus, and potassium. Bhaskar (1, p.139), in the work he carried on using Olympic and Melbourne soils, reported that small increases in growth were noted when phosphorus or nitrogen was used alone, and a marked increase in growth when phosphorus and nitrogen were used in combination.

DESCRIPTION OF THE SOILS

The Melbourne soil used in this study has been mapped as a clay loam (26, p.1722) and is from the Tark farm in Polk County, section 1, R. 5 W., T. 9 S. This soil is typical of the Melbourne series of extensive areas of the Coast Range Mountains in Western Oregon. The Olympic soil has been mapped as a clay loam (12, p.1702) and is from the Red Hill Branch Experiment Station near Oregon City in Clackamas County. This soil is typical of the Olympic series in Western Oregon.

These residual hill soils of Western Oregon occupy extensive areas of the Cascade and of the Coast Ranges and are known locally as "red hill" soils. These soils are developed on consolidated rock material and have been classified into two groups, (1) those derived from basic igneous rock consisting of basalt and diabase, and (2) those derived from sedimentary rocks consisting of sandstones and shales. The Olympic series is included in the igneous group while the Melbourne series is in the sedimentary group.

The Olympic soil series is the most extensive group of soils in Western Oregon, comprising 698,304 acres (20, p.5). These soils are characterized by a brown to reddish-brown surface soil high in iron on red to brown heavier subsoil on basalt. Iron enriched seepage veins are found in places in the subsoil. They are distinctly acid in reaction, low in available phosphorus and in total sulfur. There are variations in depth and slope. They are usually well drained, can be worked early, and do not erode seriously.

The Melbourne soil series is the second most extensive group of soils in Western Oregon, comprising 377,836 acres (20, p.5). These soils are characterized by a light-brown soil on yellowish-brown subsoil underlaid with sandstone or shale. They are distinctly acid and low in available phosphorus. They are higher in silica and have less stable crumbs and fewer iron-bearing pellets than the red soils of basaltic origin. Soil profile studies (18, p.15) of hilly Melbourne indicate that in places from one-fourth to three-fourths of the original top plow-depth soil has been eroded away. Twenty-five to thirty percent of the native supply of soil organic matter and of nitrogen have been lost from extensive areas of old cultivated land.

PLAN OF THE EXPERIMENT

Two types of methods were used to determine the phosphorus availability of the two soils: (1) biological method, (2) chemical method.

In the biological method sunflowers were used to determine plant response to phosphorus treatments. In the chemical method different solvents were used to extract the available phosphorus in the soil.

The Olympic soil was used in this study because it is representative of the soils derived from igneous rock, and because of the extensive acreage this soil occupies in Western Oregon. The Melbourne soil was selected for use in this study because it is representative of the soils derived from sedimentary materials and because of the extensive acreage it comprises.

Greenhouse Method

Biological methods involving use of small quantities of soil on which plants are grown under controlled conditions in the greenhouse have been used in an attempt to narrow the gap between soil analyses and field plot experiments. Comparative yields from the treated and untreated portions of the soil are usually taken as an index of the availability of certain plant nutrients. It is recognized that this method does not give an accurate quantitative measure of the integrated effect of the physical properties of the soil in the field, the cropping and soil management practices, or the climatic environment to which crops in the field are exposed. To this extent these biological methods are empirical, but they are still valuable tools in soil fertility research.

The A horizons of both soils were taken at random from uncultivated areas and allowed to air dry in the greenhouse until they reached a constant moisture content. They were then passed through a 1/4 inch mesh sieve. Two hundred and sixty clean No. 2 cans with four holes punched in the bottom of each for drainage were used. To 130 of these cans, one and one-half pounds of Melbourne soil, calculated on an oven dry basis, were added. The same procedure was followed with the Olympic soil. One-half of the cans from each soil series were randomly selected and to each was added 1.361 grams of $CaCO_3$. This is equivalent to two tons of lime per acre on a weight basis.[1]

Sunflowers were used in this study because they are a non-legume and because of their short growth period.

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1. The volume of soil occupying one acre to a depth of 6-7 inches or an acre-furrow-slice is commonly considered to weigh 2,000,000 pounds. All calculations in this study are based on this figure.

The following procedure was used in planting the sunflowers. The top one to one and one-half inches of surface soil was removed from each can. The remaining soil was thoroughly mixed and then watered. Ten sunflower seeds of approximately the same size were placed on the wet soil, following which the dry soil which had previously been removed was used to cover them. All the cans were then grouped together and covered with paper. On February 1, five days after planting, nearly all of the plants had sprouted.

On February 2, the cans were grouped as follows: the soils from each series were divided into three groups of forty cans each. Each group of forty cans contained twenty limed and twenty untreated soils. Each group was then subdivided into eight separate subgroups, each subgroup containing five cans of soil. Each group is then made up of four subgroups of five cans each of untreated soil and four subgroups of five cans each of lime-treated soil. The cans in each subgroup were treated as follows: can #1, no phosphorus; can #2 received 7.5 ppm of phosphorus; can #3 received 15 ppm of phosphorus; can #4 received 30 ppm of phosphorus; and can #5 received 60 ppm of phosphorus. This is one-fourth of the total amount that they received during the course of the study. The four unlimed subgroups in each group were treated as follows: subgroup #1 received no treatment; subgroup #2 received 25 ppm of nitrogen; subgroup #3 received 12.5 ppm of sulfur; and subgroup #4 received 25 ppm of nitrogen and 12.5 ppm of sulfur. The limed subgroups from each plot were treated as follows: subgroup #5 received no treatment; subgroup #6 received 25 ppm of nitrogen; subgroup #7 received 12.5 ppm of sulfur; and subgroup #8 received 25 ppm of nitrogen and 12.5 ppm of sulfur. Again this is one-fourth of the total amount of each of these elements that they received during the course of this study. These fertilizer treatments are illustrated in the following table.

TABLE I.

Fertilizer Treatments Used

P (ppm)	Nutrients added*						
	N	S	L	NS	NL	SL	NSL
P_o(0)	NP_o	SP_o	LP_o	NSP_o	NLP_o	SLP_o	$NSLP_o$
P_1(30)	NP_1	SP_1	LP_1	NSP_1	NLP_1	SLP_1	$NSLP_1$
P_2(60)	NP_2	SP_2	LP_2	NSP_2	NLP_2	SLP_2	$NSLP_2$
P_3(120)	NP_3	SP_3	LP_3	NSP_3	NLP_3	SLP_3	$NSLP_3$
P_4(240)	NP_4	SP_4	LP_4	NSP_4	NLP_4	SLP_4	$NSLP_4$

* N = 100 ppm nitrogen
S = 50 ppm sulfur
L = 2 T/Acre $CaCO_3$

Solutions of monocalcium phosphate, ammonium nitrate and of sodium sulfate were used as sources of the three nutrients, phosphorus, nitrogen and sulfur. The phosphate solution was prepared by dissolving 10.375 grams of monocalcium phosphate in distilled water and bringing the total volume up to one liter. One 2 ml application of this solution is equivalent to 7.5 ppm of phosphorus. The nitrate solution was prepared by dissolving 24.275 grams of ammonium nitrate in distilled water and bringing the volume up to one liter. One 2 ml application of this solution is equivalent to 25 ppm of nitrogen. The sulfate solution was prepared by dissolving 37.75 grams of sodium sulfate in distilled water and bringing the volume up to one liter. One 1 ml application of this solution is equivalent to 12.5 ppm of sulfur.

Use of the following formula will give the total grams of any particular fertilizer that needs to be applied to any one can.

Example:

$$\frac{(100\#N/A)(1.5\#\ soil/can)}{(2{,}000{,}000\#\ soil/A)} \times \frac{(453.59\ gms/\#)(80.05\ mole.wt.\ of\ NH_4NO_3)}{(28.02\ wt.\ of\ N\ in\ NH_4NO_3)}$$

$= .0971$ gms. NH_4NO_3/can of soil.

On each of the following dates, February 16, 29 and March 15, the groups were again treated. Each time the plants were fertilized the cans in each group were rerandomized.

On February 6 the plants were thinned to six per can and on February 16 they were thinned to four plants.

In the greenhouse the cans containing the plants were placed on large tables in rows. Those with the Olympic soil were placed on one table and those with the Melbourne soil on another. There were four inches between cans in the rows and ten inches between rows. Ten extra cans of each soil series were placed at the south end of the table as border rows to eliminate in part the variation due to placement.

Watering of the plants was done on the basis of need as determined by visual observation. Many of the cans needed to be watered twice a day during the latter part of the experiment; there were others which needed water only once every second or third day.

March 26 the plants from all the cans were harvested. Two random samples of two plants each were taken from each of the cans and placed in separate marked envelopes. They were then placed in an oven and allowed to dry for 60 hours at 60°C. They were then removed from the oven and the plants were weighed to the nearest .01 gram. The weights were then analyzed statistically to determine if there were any significant differences between treatments.

Chemical Methods

Determination of Available Phosphorus in Soils. During the last half century, soil scientists have been in search of a chemical method that would accurately differentiate the different forms of soil phosphorus for the purpose of determining the phosphorus needs of soils. Since Truog and Meyer (28, pp.137-138) presented their modification of the Denige's colormetric method for phosphorus determinations, a great amount of work has been done on phosphate determinations using different types of solvents. In this study four different extractants were used to determine available phosphates. These determinations were made on each of the treated soils after cropping. The methods used are as follows:

(1) Carbonic Acid Method. The method used in Idaho and described by Smith (24, p.4) in which CO_2 is bubbled through a soil water suspension was used.

(2) Sulfuric Acid (0.002N) Method. The .002N sulfuric acid method as described by Truog (27, pp.879-881) was used.

(3) Sodium Acetate Method. The method used by Pennsylvania State College as described by Merkle (16, pp.5-6) was used.

(4) Bray #1 Method. This method as suggested by Bray (3, p.42) and which is used by Graham (7, pp.9-10) with slight modifications was used. A boric acid solution was used as suggested by Kurtz (13, p.855) to eleminate the fluoride ion interference.

Determination of Readily Available Potassium. The method used by Pennsylvania State College as described by Merkle (16, p.5) was used.

Soil Organic Matter. The method proposed by Walkley and Black (29, pp.36-37) was used to determine the organic matter content of the soils.

Lime Requirement. The modified Comber (25, p.40) test as proposed by Harper (8, p.75) was used.

Soil Reaction. The pH of the soils was determined using a Beckman pH meter (glass electrode, thick paste).

RESULTS

Greenhouse Results

Plant Response on Olympic Soil. There is a significant increase in the growth of the sunflowers which are treated with both nitrogen and phosphorus. Sulfur and lime alone or in combination with nitrogen or phosphorus, or both do not increase the yield of the sunflowers, Table III. It will be noted that nitrogen x phosphorus has a significant "f" value. A comparison of the mean yields show that nitrogen or phosphorus when used alone does not increase yield, Table IV. When nitrogen is present increasing increments of phosphorus result in significant increases in yields. See Figures 1, 3, and 5.

Plant Response on Melbourne Soil. Results on this soil are the same as shown on the Olympic soil. See Tables V and VI, and Figures 2 and 4.

When nitrogen in combination with sulfur or lime, or both was used at phosphorus rates of 60 ppm and above, the sunflowers exhibited boron deficiency symptoms. The plants in the two cans on the left in Figure 6 show the typical boron deficiency symptoms. Typical symptoms include stunted growth, a frosted appearance of the terminal growth leaves which is followed by a back curling of the leaves, and a blackening of the terminal growth. As shown in Table VII, a noticeable decrease in yield was observed at the 240 ppm phosphorus application.

Yield Comparison. The yield comparison of the plants grown on the Olympic soil with those growing on the Melbourne soil shows that the Olympic soil is more productive, Table II. Differences in total yields of the plants grown on soils not receiving phosphorus were 30.35 grams. Differences in yield on those receiving 240 ppm of phosphorus amounted to 48.68 grams. All yields on the Olympic soil were higher than those on the Melbourne soil.

TABLE II.

Yield Comparison - Melbourne, Olympic Soil

Rate of Phosphorus	Total Yield		
	Olympic	Melbourne	Difference
ppm	grams	grams	grams
0	68.80	38.45	30.35
30	93.36	50.10	43.26
60	107.21	74.27	32.94
120	118.59	80.81	37.78
240	127.40	78.72	48.68

Nitrogen Deficiency. Nitrogen is more of a limiting factor on the Olympic soil than it is on the Melbourne soil as shown in Table VII. Visual nitrogen deficiency symptoms were observed on the plants growing on the Olympic soils before phosphorus was added. Nitrogen deficiency symptoms appeared in the plants growing on the Melbourne soil only after they were fertilized with phosphorus.

Chemical Results

Sodium Acetate. The phosphorus extracting range of this solution is very narrow, Table VIII. The average amount of phosphorus extracted from the Melbourne soil where no phosphorus had been added, after cropping was 10.6 ppm as compared to 11.6 ppm for the Olympic. The average amount of phosphorus extracted from the Melbourne soil which had received 240 ppm of phosphorus after cropping was 19.1 ppm as compared to 20 ppm for the Olympic soil. The difference in the amount of phosphorus extracted from these two treatments is 8.5 ppm and 8.4 ppm.

Carbonic Acid. Similar results, Table VIII, were obtained with this extractant on the soils receiving no phosphorus and those receiving 240 ppm phosphorus, also indicating a very narrow range for this method. For the

Melbourne soil the range is 7.8 ppm of phosphorus and for the Olympic, 6.8 ppm.

Dilute Sulfuric Acid. The phosphorus extracting range of this solvent is wider than either the carbonic acid or the sodium acetate method. For the Melbourne soil the range is 38.7 ppm while the range on the Olympic soil is 47.5. There is, however, considerable variation in the amount of phosphorus extracted from soils which received the same amount of phosphorus, Table VIII.

Bray #1 Method. This method has a wide extracting range. The range for the Melbourne soil is from 18.1 to 199.3 ppm or a difference of 181.2 ppm. The range for the Olympic soil is from 18.1 to 169.1 ppm or a difference of 151.1 ppm of phosphorus. Variation in the amount of phosphorus extracted from soils which received the same amount of phosphorus is not excessive, Table VIII.

Potassium. Both soils have an abundant supply of potassium. Availability for the Olympic soil is 128 ppm as compared to 135 ppm for the Melbourne.

Lime Requirement. The Olympic soil has a one ton lime requirement. The Melbourne soil has a two ton lime requirement.

Soil Reaction. The Olympic soil has a pH of 5.01. The Melbourne soil has a pH of 4.95. Application of

2 Ton/Acre of $CaCO_3$ raised the pH of the soil at least 0.5 pH.

Correlation of Greenhouse Results and Chemical Results.

Bray #1 vs. Yield. This correlation as shown in Table IX is highly significant. The amount of phosphorus extracted by this method increases as the yield of the sunflowers grown on the Olympic and Melbourne soils increases.

TABLE III.

Analyses of Variance of Yield in Grams of Sunflowers Grown on Olympic Soil

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	f
Replication	.286	2	.143	-
P	44.139	4	11.035	1.48
N	99.562	1	99.562	13.38
S	.265	1	.265	2.64
L	1.014	1	1.014	2.21
PxN	29.758	4	7.439	74.06*
PxS	.159	4	.040	.40
PxL	.141	4	.035	.35
NxS	.186	1	.186	1.85
NxL	.460	1	.459	4.57
SxL	.333	1	.333	3.32
PxNxS	.505	4	.126	1.26
PxNxL	.050	4	.012	.12
PxSxL	.209	4	.052	.52
NxSxL	.005	1	.005	.05
PxNxSxL	.089	4	.022	.22
Exp. Error	7.122	78	.091	.91
Within Plot	12.054	120	.100	-
TOTAL	196.337	239		

* Significant increase in yield.

TABLE IV.

Mean Yields in Grams - Olympic Soil

Nitrogen	Phosphorus				
	0 ppm	30 ppm	60 ppm	120 ppm	240 ppm
0 ppm	1.365	1.477	1.538	1.545	1.590
100 ppm	1.502	2.412	2.929	3.396	3.718

$LSD_{.05} = 0.181$

TABLE V.

Analyses of Variance of Yield in Grams of Sunflowers Grown on Melbourne Soil

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	f
Replication	.456	2	.228	-
P	26.138	4	6.535	1.27
N	76.309	1	76.309	14.79
S	.326	1	.326	.56
L	4.243	1	4.243	7.30
PxN	20.636	4	5.159	80.44*
PxS	.131	4	.033	.51
PxL	.485	4	.121	1.89
NxS	.082	1	.082	.14
NxL	1.089	1	1.089	1.87
SxL	.231	1	.231	.40
PxNxS	.389	4	.097	1.52
PxNxL	.268	4	.067	1.05
PxSxL	.275	4	.069	1.07
NxSxL	.581	1	.581	9.06
PxNxSxL	.296	4	.074	1.15
Exp. Error	2.668	78	.034	.53
Within Plot	7.697	120	.064	-
TOTAL	142.304	239		

* Significant increase in yield.

TABLE VI.

Mean Yields in Grams - Melbourne Soil

Nitrogen	Phosphorus				
	0 ppm	30 ppm	60 ppm	120 ppm	240 ppm
0 ppm	.745	.802	.874	.847	.815
100 ppm	.858	1.660	2.220	2.520	2.465

$LSD_{.05} = 0.145$

TABLE VII.

Yield, pH, and Deficiency Symptoms as Related to Phosphorus Supply

Phosphorus (ppm)		Melbourne Clay Loam			Olympic Clay Loam		
		Yield (3 Plots) grams	pH	Visual* Def. Symptoms	Yield (3 Plots) grams	pH	Visual* Def. Symptoms
				Check Subgroup			
0		3.12	4.97	- - -	7.39	5.26	N - -
30		3.75	4.95	N - -	8.00	5.20	N - -
60		3.84	4.90	N - -	8.43	5.22	N - -
120		4.03	4.90	N - -	8.18	5.19	N - -
240		3.76	4.91	N - -	8.69	5.13	N - -
	Total	18.49			40.69		
	Average	3.70	4.93		8.13	5.20	
				Sulfur (50 ppm) Subgroup			
0		3.90	4.94	- - -	7.50	5.20	N P -
30		3.61	5.00	N - -	9.04	5.19	N P -
60		3.70	4.98	N - -	8.97	5.20	N - -
120		3.74	4.95	N - -	8.98	5.19	N - -
240		3.55	4.86	N - -	8.49	5.15	N - -
	Total	18.50			42.98		
	Average	3.70	4.95		8.60	5.19	
				Lime (2000 ppm) Subgroup			
0		5.21	5.78	- - -	8.58	5.71	N P -
30		5.23	5.79	N - -	8.94	5.80	N P -
60		6.72	5.85	N - -	10.23	5.80	N - -
120		6.38	5.84	N - -	9.72	5.71	N - -
240		5.88	5.79	N - -	11.71	5.80	N - -
	Total	29.42			49.18		
	Average	5.88	5.81		9.84	5.76	

* N = Nitrogen deficient
P = Phosphorus deficient
B = Boron deficient

TABLE VII. (Cont'd.)

Yield, pH, and Deficiency Symptoms as Related to Phosphorus Supply

Phosphorus (ppm)		Melbourne Clay Loam			Olympic Clay Loam		
		Yield (3 Plots) grams	pH	Visual* Def. Symptoms	Yield (3 Plots) grams	pH	Visual* Def. Symptoms
		Sulfur (50 ppm) and Lime (2000 ppm) Subgroup					
0		5.65	5.71	- - -	9.28	5.75	N P -
30		6.68	5.68	N - -	9.48	5.83	N P -
60		6.72	5.61	N - -	9.29	5.69	N - -
120		6.19	5.75	N - -	10.21	5.75	N - -
240		6.37	5.61	N - -	9.28	5.62	N - -
	Total	31.61			47.54		
	Average	6.32	5.67		9.51	5.73	
		Nitrogen (100 ppm) Subgroup					
0		4.75	4.80	- P -	8.50	5.04	- P -
30		9.49	4.89	- P -	14.09	5.03	- P -
60		10.61	4.87	- - -	16.74	5.01	- - -
120		13.01	4.87	- - -	19.72	5.01	- - -
240		14.44	4.85	- - -	20.97	5.01	- - -
	Total	52.30			80.02		
	Average	10.46	4.86		16.00	5.02	
		Nitrogen (100 ppm) and Sulfur (50 ppm) Subgroup					
0		4.76	4.92	- P -	9.42	5.13	- P -
30		10.59	4.92	- P -	14.56	5.09	- P -
60		14.14	4.88	- - B	18.50	5.09	- P -
120		15.56	4.82	- - B	20.72	5.03	- - -
240		15.39	4.80	- - B	22.99	5.03	- - -
	Total	60.44			86.19		
	Average	12.09	4.87		17.24	5.07	

* N = Nitrogen deficient
P = Phosphorus deficient
B = Boron deficient

TABLE VII. (Cont'd.)

Yield, pH, and Deficiency Symptoms as Related to Phosphorus Supply

Phosphorus (ppm)		Melbourne Clay Loam			Olympic Clay Loam		
		Yield (3 Plots) grams	pH	Visual* Def. Symptoms	Yield (3 Plots) grams	pH	Visual* Def. Symptoms
		Nitrogen (100 ppm) and Lime (2000 ppm) Subgroup					
0		5.37	5.51	- P -	9.12	5.68	- P -
30		9.89	5.51	- P -	14.50	5.62	- P -
60		14.63	5.49	- - B	16.86	5.66	- P -
120		15.71	5.51	- - B	20.60	5.65	- - -
240		15.45	5.40	- - B	22.72	5.64	- - -
	Total	61.05			82.80		
	Average	12.21	5.48		16.56	5.65	
		Nitrogen (100 ppm) and Sulfur (50 ppm) and Lime (2000 ppm) Subgroup					
0		5.71	5.49	- P -	9.01	5.72	- P -
30		9.87	5.70	- P -	14.75	5.62	- P -
60		13.91	5.48	- - B	18.19	5.53	- P -
120		16.19	5.51	- - B	20.46	5.57	- - -
240		13.88	5.54	- - B	22.55	5.75	- - -
	Total	59.46			84.96		
	Average	11.89	5.54		16.99	5.64	

* N = Nitrogen deficient
P = Phosphorus deficient
B = Boron deficient

TABLE VIII.

Phosphorus in ppm Extracted by Different Solvents After Fertilizing and Cropping

Fertilizer* Treatment	Melbourne Clay Loam				Olympic Clay Loam			
	Sodium Acetate	CO_2	.002N H_2SO_4	.03N NH_4F in .025N HCl	Sodium Acetate	CO_2	.002N H_2SO_4	.03N NH_4F in .025N HCl
Phosphorus - 0 ppm								
Check	7.5	17.5	15.0	12.5	12.5	22.5	10.0	19.0
S	10.0	17.5	15.0	17.5	10.0	15.0	20.0	21.0
L	15.0	12.5	10.0	23.0	12.5	17.5	20.0	17.5
N	10.0	17.5	10.0	23.0	12.5	15.0	20.0	16.0
SL	10.0	12.5	15.0	22.5	10.0	15.0	20.0	13.0
NS	12.5	22.5	10.0	14.0	12.5	25.0	15.0	23.0
NL	10.0	15.0	30.0	17.5	10.0	17.5	20.0	16.0
NSL	10.0	15.0	15.0	15.0	12.5	17.5	25.0	19.0
Average	10.6	15.0	15.0	18.1	11.6	17.6	18.7	18.1
Phosphorus - 30 ppm								
P	10.0	15.0	20.0	24.5	12.5	22.5	15.0	38.5
S	10.0	17.5	20.0	33.5	10.0	17.5	25.0	32.0
L	10.0	15.0	15.0	40.5	12.5	17.5	20.0	26.5
N	10.0	15.0	15.0	40.0	15.0	17.5	25.0	30.0
SL	10.0	15.0	20.0	52.0	10.0	15.0	25.0	23.0
NS	12.5	22.5	15.0	33.0	10.0	22.5	20.0	32.0
NL	12.5	17.5	25.0	55.0	10.0	20.0	25.0	27.0
NSL	15.0	17.5	20.0	31.0	12.5	17.5	25.0	27.0

TABLE VIII. (Cont'd.)

Phosphorus in ppm Extracted by Different Solvents After Fertilizing and Cropping

Fertilizer* Treatment	Melbourne Clay Loam				Olympic Clay Loam			
	Sodium Acetate	CO_2	.002N H_2SO_4	.03N NH_4F in .025N HCl	Sodium Acetate	CO_2	.002N H_2SO_4	.03N NH_4F in .025N HCl
Phosphorus - 60 ppm								
P	15.0	17.5	20.0	52.5	15.0	22.5	25.0	52.5
S	12.5	17.5	20.0	46.0	10.0	17.5	25.0	44.0
L	12.5	15.0	20.0	60.0	15.0	17.5	25.0	52.0
N	15.0	17.5	20.0	66.5	15.0	17.5	30.0	51.0
SL	10.0	15.0	40.0	66.0	12.5	15.0	25.0	55.0
NS	12.5	22.5	30.0	62.0	15.0	25.0	25.0	49.0
NL	15.0	20.0	25.0	59.0	10.0	17.5	35.0	50.0
NSL	12.5	17.5	45.0	57.0	12.5	20.0	30.0	51.0
Phosphorus - 120 ppm								
P	10.0	17.5	25.0	67.0	12.5	20.0	50.0	78.0
S	15.0	20.0	30.0	69.0	12.5	20.0	50.0	79.0
L	15.0	15.0	25.0	80.0	15.0	20.0	45.0	83.0
N	15.0	17.5	25.0	95.0	12.5	17.5	35.0	97.0
SL	12.5	17.5	40.0	87.0	12.5	20.0	35.0	81.0
NS	15.0	25.0	35.0	91.0	17.5	20.0	35.0	88.0
NL	15.0	17.5	40.0	63.0	15.0	17.5	40.0	87.0
NSL	12.5	17.5	40.0	99.0	17.5	20.0	40.0	79.0

TABLE VIII. (Cont'd.)

Phosphorus in ppm Extracted by Different Solvents After Fertilizing and Cropping

Fertilizer* Treatment	Melbourne Clay Loam				Olympic Clay Loam			
	Sodium Acetate	CO_2	.002N H_2SO_4	.03N NH_4F in .025N HCl	Sodium Acetate	CO_2	.002N H_2SO_4	.03N NH_4F in .025N HCl
Phosphorus - 240 ppm								
P	12.5	22.5	55.0	168.0	22.5	25.0	60.0	158.0
S	15.0	25.0	55.0	150.0	20.0	22.5	70.0	167.0
L	25.0	20.0	50.0	238.0	22.5	25.0	70.0	168.0
N	20.0	20.0	45.0	197.5	17.5	25.0	70.0	168.0
SL	20.0	20.0	55.0	222.5	22.5	25.0	65.0	178.0
NS	17.5	30.0	60.0	217.0	17.5	25.0	55.0	171.0
NL	22.5	22.5	55.0	197.5	20.0	22.5	70.0	159.0
NSL	20.0	22.5	55.0	204.0	17.5	25.0	70.0	184.0
Average	19.1	22.8	53.7	199.3	20.0	24.4	66.2	169.1

* Fertilizer Treatment:

N = 100 ppm nitrogen = 200 lbs per acre
S = 50 ppm sulfur = 100 lbs per acre
L = 2 T/Acre $CaCO_3$

TABLE IX.

Analysis of Co-variance

Melbourne Soil - Phosphorus Extracted vs. Plant Growth*							
Variation due to	d.f.	x^2	xy	y^2	x^2	xy	y^2
Total	19	86,732.55	3,391.97	298.40			
Between Treatments	4	85,224.43	3,428.57	279.27	21,306.11	857.14	69.82
Within Treatments	15	1,508.12	-36.61	19.13	100.54	-24.40	1.27

$$\frac{xy}{\sqrt{x^2}\sqrt{y^2}} = r = .70$$ **Highly significant

Olympic Soil - Phosphorus Extracted vs. Plant Growth*							
Variation due to	d.f.	x^2	xy	y^2	x^2	xy	y^2
Total	19	61,156.11	4,390.86	444.69			
Between Treatments	4	60,617.93	4,394.22	438.49	15,154.48	1,098.55	109.62
Within Treatments	15	538.19	- 3.36	6.20	35.88	- .22	.41

$$\frac{xy}{\sqrt{x^2}\sqrt{y^2}} = r = .85$$ **Highly significant

* Phosphorus extracted by Bray #1 Method

TABLE X.

Chemical Analysis of Olympic Clay Loam
and Melbourne Clay Loam

Soil	Depth Inches	% Organic Matter	pH	Lime Require-ment*	Avail-able K ppm	Avail-able P ppm**
Olympic	0-7	4.08	5.01	Slight	128	29.0
Melbourne	0-7	3.09	4.95	Medium	135	12.5

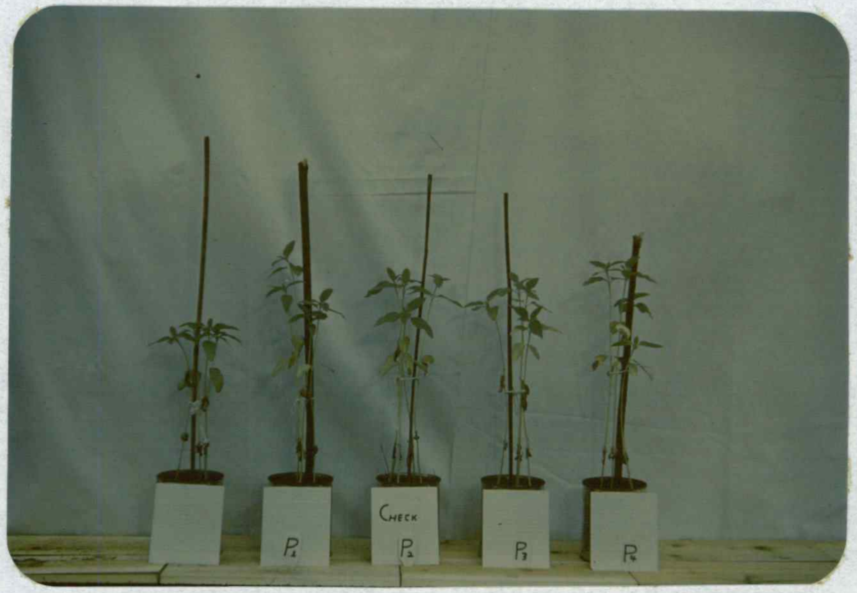
* Slight lime requirement = 1 Ton/Acre $CaCO_3$
Medium lime requirement = 2 Tons/Acre $CaCO_3$

** Bray #1 Method

Figure 1.

Olympic Soil - Check Group

Figure 2.



Melbourne Soil - Check Group

Figure 3.

Olympic Soil - Nitrogen Group

Figure 4.

Melbourne Soil - Nitrogen Group

Figure 5.

Olympic Soil - Nitrogen-Sulfur-Lime Group

Figure 6.

Melbourne Soil - Nitrogen-Sulfur-Lime Group

DISCUSSION

Phosphorus Requirement. Maximum plant growth under a given set of environmental conditions is produced only when all essential nutrients are present in adequate amounts of available forms. A soil which is lacking in any essential nutrient in the required amount is said to be limiting in that nutrient. A soil that contains sufficient available phosphorus for maximum yields has a zero phosphorus requirement.

The determination of the available phosphorus requirement and of other essential nutrients by chemical test is a phase of soil research that has received much attention. In the mind of the general public these tests are frequently overrated. They are of distinct value, though, when properly interpreted.

Greenhouse Results

The significant interaction between nitrogen and phosphorus on both the Olympic and Melbourne soils, Tables III and IV, can be attributed to the low available supply of both of these nutrients. Nitrogen and phosphorus are both so deficient in these soils that the addition of either one alone did not increase yields. This is in agreement with the results obtained by Baskar (1, p.139). When nitrogen is supplied, increased increments of phosphorus result in increased yields. The phosphorus requirement for both the Olympic and Melbourne soils at a 100 ppm level of nitrogen, disregarding the effect of boron deficiency, is above 240 ppm. The estimated minimum level, Table VII, to produce plants not exhibiting any signs of phosphorus deficiency, is 120 ppm of phosphorus.

Nitrogen is more of a limiting factor on the Olympic soil than on the Melbourne soil. The sunflowers grown on the Melbourne soil showed nitrogen deficiency symptoms (light green color) only after phosphorus was added, Table VII. The plants grown on the Olympic soil in all cases showed characteristic nitrogen deficiency symptoms before phosphorus was added to the soil.

Boron Deficiency. The sunflowers grown on the Melbourne soil receiving nitrogen, and phosphorus, at the higher rates 60-240 ppm, plus lime or sulfur or both, showed marked boron deficiency symptoms, Table VII. The plants were stunted and had malformed terminal leaves. This type of boron deficiency in plants is described by Schuster and Stephenson (22, pp.609-610). Boron deficiencies develop and are more marked at the upper levels of phosphorus application when nitrogen in combination with lime or sulfur or both is supplied.

Yield Comparison. The total yields of the plants growing on the Melbourne soils are lower than those on the Olympic, Table II, indicating the Olympic soil to be more productive. In all the greenhouse work the Olympic soil was consistently easier to work and more friable than the Melbourne. This may be due in part to the higher organic matter content.

The Olympic soil has approximately one percent more organic matter than the Melbourne. Chemical analyses of these soils, Table X (p.33) show that the Olympic has 16.5 ppm more available phosphorus than the Melbourne soil, and a one ton lime requirement. The Melbourne soil has a two ton lime requirement. Difference in yield can be attributed in part to the higher percent of organic matter, more readily available phosphorus, and a lower lime requirement.

The sunflower seeds planted germinated and came through the soils at about the same time, but the rate of growth of the plants on the Olympic soil was much faster than that of the plants on the Melbourne soil.

It should be emphasized that in all of the work that has been done on these two soils the top layer of soil (6-7 inches) was used. While the conclusions which can be drawn from this study will be indicative of what can reasonably be expected in the field, the importance of the subsoil should not be overlooked, since the entire root zone area is important in the production of a plant.

Chemical Test Results

There are many different extraction reagents being used with varying success in different parts of the country. The first requirement of a good extracting solution is that it should extract the total amount (or a proportionate part) of the available form or forms of a nutrient from soils with variable properties. Four solvents, carbon dioxide, sodium acetate, dilute sulfuric acid, and ammonium fluoride, were used in this study to determine their relative efficiency for determining available phosphorus in the soils.

Of the four chemical methods used in this study the ammonium fluoride method proved satisfactory. This method has a wide extracting range and a relatively small variation in the amount of phosphorus extracted from soils receiving the same amount of phosphorus fertilizer, Table VIII.

As mentioned previously, the "fixation" of phosphorus on the red hill soils is not uncommon. The Bray #1 method as developed by Bray (3, p.42) removes a part of this fixed phosphorus. The mechanism is one of replacement or exchange. The fluoride ions replace the phosphate ions held in the soil. It is, therefore, the result of the replacement action of the fluoride ion in the ammonium fluoride method that makes it so effective.

The highest yields on the Melbourne soil were produced on those soils which according to the ammonium fluoride method tested in excess of 63 ppm available phosphorus. Highest yields on the Olympic were obtained on soils that tested above 159 ppm available phosphorus. The figures 63 and 159 are used because yield increases are most significant above these points.

Correlation of Phosphorus Extracted vs. Yield. The correlation figures or "r" values shown in Table IX are significant. As the amount of phosphorus extracted from the Olympic and Melbourne soil increased, the yield of the sunflowers grown on these soils increased.

In running the correlation, Table IX, the following factors were considered: (1) ammonium fluoride was the only method used since it seems to more nearly characterize the available phosphorus conditions in the soil; (2) the correlation was made with only those samples which had been treated with nitrogen, since these were the only treatments that showed a significant increase in growth with increased additions of phosphorus. The

Bray #1 method is an excellent method for estimating the phosphorus needs of the Melbourne and Olympic soils. This method should be of considerable value for estimating phosphorus needs in the field when the necessary correlation work is available.

SUMMARY AND CONCLUSIONS

1. An estimate of phosphorus availability on two "red hill" soils of Western Oregon was obtained by: (1) growing sunflowers on these soils in the greenhouse and determining their response to increments of phosphorus alone and in combination with other nutrients; (2) comparing plant response to the amount of phosphorus extracted by four different solvents.

2. For determining available phosphorus on the Olympic and Melbourne soils, the Bray #1 method is superior to the carbonic acid, to the dilute sulfuric acid, or to the sodium acetate. It has a wide extracting range and less variation in the amount of phosphorus extracted.

3. The highest yields on the Melbourne soils were produced on those soils which according to the Bray #1 method tested in excess of 63 ppm available phosphorus. Highest yields on the Olympic were obtained on soils that tested above 159 ppm available phosphorus.

4. The correlation of plant growth versus phosphorus extracted from the soil using the Bray #1 method was highly significant.

5. When nitrogen is added, the Olympic soil has a phosphorus requirement above 240 ppm and the Melbourne soil has a phosphorus requirement above 120 ppm.

6. There was a significant response to the nitrogen x phosphorus combination on both soils.

7. There was no significant plant response to nitrogen, phosphorus, sulfur, or lime, when used alone. There was no significant plant response on either soil to the following combinations: nitrogen x sulfur; phosphorus x sulfur; nitrogen x sulfur x lime; phosphorus x sulfur x lime.

8. When nitrogen is added, plants growing on the Melbourne soil exhibited boron deficiency symptoms at the three highest rates of phosphorus when in combination with lime, sulfur, or both.

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