RELATION BETWEEN PLANT AVAILABLE PHOSPHATE AND PHOSPHATE EXTRACTED BY SODIUM ACETATE BUFFER IN IRRIGATED ROCKY MOUNTAIN SOILS

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The improved sodium acetate buffer method for determination of plant available phosphate was published in 1937.[1] The method makes no attempt to measure the absolute quantity of available phosphate in the soil. Rather, it is designed to show the relation between the total easily soluble phosphate in the soil and the readiness with which it may be released from the soil. Both of these factors are of importance in determining the ability of the plant to obtain its phosphate requirements.

The concentration of phosphate in the acetate buffer extract of the soil varies with the ratio of buffer to soil employed and very often it does not vary inversely with this ratio over the range of extraction rations generally used. And all soil samples which have been tested show a decrease in phosphate content of the extract if a sufficiently low buffer to soil extraction ratio is used. The forces tending to release phosphate into solution become weak compared to those tending to keep it out of solution when the concentration of soil in the mixture becomes high enough. This same phenomenon is exhibited when water only is used for extraction. In order to gain an idea of both the level of easily soluble phosphate in the soil, and the tenacity with which it is held by the soil, the acetate buffer method employs extraction of the soil at two buffer to soil ratios, namely, 5 to 1 and 20 to 1 parts buffer to soil.

Empirical standards for grading soils as sufficient, doubtful and deficient in phosphate have been set up. These standards provide satisfactory measurement for the large majority of the soils in the territory served by The Great Western Sugar Company. Many soils from the Salt River Valley in Arizona are not correctly graded by these standards.

It is the purpose of this paper to show the relation between the extractable phosphate and plant available phosphate in the various soils encountered.

ANALYSES OF REPRESENTATIVE SAMPLES

Tables I, II and III present the results of phosphate tests on a variety of representative soils from the area under consideration. These samples have been selected from a large number which have been subjected to special investigation. They cover the range from excess phosphate to severe deficiency. On many of the soils field trials have been made. On others results of Neubauer tests are available. Some figures on water soluble phosphate at various extraction ratios are also presented. On all samples the results of extraction with acetate buffer at least two buffer to soil ratios (5/1 and 20/1) are shown, and results of extraction at other ratios are shown on many.

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1. Proc. Soil Sci. Soc. Amer. Vol. 2, p. 185.

The group of eight samples in Table I includes the common loam and sandy loam soils of northern Colorado and western Nebraska. The phosphate content of the acetate buffer extract obtained at the 5/1 buffer to soil ratio is invariably greater than that of the 20/1 ratio extract, but except in abnormally high phosphate soils the phosphate content of the 5/1 extract is not twice as high as the phosphate content of the 20/1 ratio extract. The first in the list is a very fertile soil. The second is also a high yield soil and shows a sufficiency by all methods used (acetate buffer, Winogradsky, Neubauer and K_2CO_3 solution). However, the excess of phosphate is not great and fertility is maintained by regular use of manure and treble superphosphate. Next in the list are two samples in the doubtful range. In field trials one of these indicated no deficiency and the other gave a very slight, though not statistically significant, response. Two of the last three samples were shown to be definitely deficient by field trials. The last in the list is a poor, severely deficient soil.

On soils of this type the correlation between phosphate content of the acetate buffer extract and plant available phosphate is simple. And the result of extraction at single buffer to soil ratio could be employed to classify the soil as to available phosphate grade.

The second group of eight soils in Table II is representative of the Wyoming area. Soils showing similar reactions are found in extreme western Nebraska and in the deficient clay and heavy clay loam soils in Colorado.

Only when the soil is very high in phosphate does the 5/1 ratio buffer extract contain a decidedly higher concentration of phosphate than does the 20/1 ratio extract, and generally the 5/1 ratio extract is definitely the lower in phosphate concentration. All the soils listed show rather high phosphate concentrations in the buffer extracts. Soils yielding extracts with much lower phosphate concentrations are common, but they are very deficient and a discussion of them is unnecessary. The soils listed in Table II yield extracts, at the 20/1 ratio, high in phosphate. Only the first in the list yields a 5/1 ratio extract of definitely higher phosphate concentration. Fields in this area are generally deficient and this is one of the few which have been built up in fertility sufficiently to give the tests, and also the crop yields, of rich soils. Other fields of the same farm, not so fertile, give tests similar to those on No. 2 of this group. Soils Nos. 2, 3, 4 and 5 all give similar tests by acetate buffer extraction and are listed in order of decreasing Neubauer test. No. 5 was subjected to careful field trials and gave response to phosphate treatment. Samples 6, 7 and 8 yield extracts at 5/1 ratio definitely lower in phosphate than at the 20/1 ratio. Phosphate deficiency is severe as is shown by the Neubauer tests, though good beet yields are obtained on 6 and 7 by phosphating each beet crop.

When the original acetate buffer method was published in 1932,[1] only the results of extraction at 5/1 ratio were used for grading soils. By the standards in use at that time soils such as Nos. 2, 3, 4, 5 and 8 in this group were placed in the doubtful class and those such as Nos. 6 and 7 were placed in the deficient class. Further studies at various extraction ratios and on a wider range of samples brought about a revision of the testing and grading method, as published in 1937.[2]

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1. Jour. Am. Soc. Agr., Vol. 24, No. 6.
2. Proc. Soil Soc. of Amer., Vol. 2, p. 185.

The present grading standards still place soils such as 2, 3, 4 and 5 in the doubtful group. Not all evidence regarding deficiency in these soils is in agreement. Only one field has been subjected to positive field trial. Deficiency was demonstrated. The fields from which these samples were taken are regularly phosphated for beets and the growers are satisfied that the treatment more than repays its cost, though no comparisons of phosphated with non-phosphated areas are made. Neubauer tests show the soils low (from 3 to 5 mg. P_2O_5 per 100 gms. soil) in phosphate, while the soils such as Nos. 6 and 7 are definitely lower, at about 2 or less mg. P_2O_5 per 100 gms. soil. Pot tests on soils such as Nos. 2, 3, 4 and 5 have not demonstrated definite deficiency, while on soils such as Nos. 6 and 7 deficiency is shown with certainty. There is one important reason for giving little weight to the pot test results on these higher testing soils. Extraction at high buffer to soil ratios shows they are very high in easily soluble phosphate. Extraction at the 5/1 ratio shows that much of this phosphate is strongly bound in the soil complex and therefore not available at the high level. In pot tests the dense root system probably greatly increases the CO_2 content of the soil atmosphere above the normal in these soils, of low organic matter content, in the field and the level of available phosphate is probably raised by solution of easily soluble phosphate in the high CO_2 areas in the pots. If we ignore results of pot tests, all evidence points to deficiency in these soils, though not so severe as in soils of the same type but yielding an extract of low phosphate content at the 5/1 buffer to soil ratio.

The soils in Table III are from the Salt River Valley of Arizona. A few soils from other areas in Arizona have given similar results. The level of extractable phosphate is far higher than that in Colorado and Wyoming soils. A few field trials have demonstrated phosphate deficiency and very heavy phosphate applications have become standard practice. Crops are valuable and growers are satisfied with results. We have very little correlation between field trials and acetate buffer tests to guide us in setting standards, but a number of Neubauer tests are available. On the basis of the Neubauer test, the first sample in the list contains a sufficiency of phosphate, Samples Nos. 2 and 3 are questionable, and Nos. 4, 5 and 6 are definitely deficient. The most striking feature of these soils, compared to the Colorado and Wyoming soils, is the wide range of extraction ratios over which the phosphate content of the extract may remain practically constant at a high level, as shown in No. 7 in the list. Even on the very sandy soils, such as No. 5 in the list, the phosphate content of the 5/1 ratio extract is not more than twice that of the 20/1 ratio extract, except in soils of very high phosphate content. There can be no question that there is a different relation between buffer extractable phosphate and available phosphate in Arizona and Colorado soils. A Colorado soil giving the buffer test of Sample No. 5886 would unquestionably be high in plant available phosphate. This sample tests deficient by Neubauer, Windogradsky and Hockensmith* tests. The third sample in the list is still higher in readily soluble phosphate. This sample tests doubtful by Neubauer, Winogradsky and Hockensmith tests. Not many samples have been found giving extracts so high in phosphate and at the same time extracts of lower phosphate concentration at the 5/1 ratio than at the 20/1 ratio, as No. 2 in the list. This sample tests doubtful by Neubauer and indicates a very slight deficiency by winogradsky method.

In general the Arizona soils show much higher level of extractable phosphate than do Colorado and Wyoming soils at the same level of available phos-

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* P_2O_5 soluble in 1% K_2CO_3 solution.

phate. This is true whether distilled water, CO_2 saturated water, acetate buffer or K_2CO_3 solution is used for extraction. A discussion of this subject is not in place here, but McGeorge and Breazeale[1] have offered an explanation.

The eighth sample in the list in Table III is an example of one which shows excessive capacity for maintaining the level of extractable phosphate at high buffer to soil ratios. This soil yields an extract at 50/1 ratio containing a higher phosphate concentration than is yielded at 20/1 or 5/1 ratio. The sample is a severely deficient California soil which has very great capacity for reversion of added phosphate.

EXTRACTABLE PHOSPHATE AND RESPONSE TO PHOSPHATE FERTILIZATION

Empirical standards have been set up for classification of soils as sufficient, doubtful and deficient by the acetate buffer test. These standards are primarily for use by those who are unfamiliar with the known relations between available and extractable phosphate. Under these standards a soil which yields extracts at the 5/1 and 20/1 ratios containing 1.5 and 1.4 p.p.m. of P respectively is graded sufficient, while another soil yielding extracts containing 1.4 and 1.5 p.p.m. of P at the 5/1 and 20/1 ratios respectively is classed as doubtful. Actually there is negligible difference in the available phosphate content of the two soils and response to phosphate fertilization will be controlled by other factors. In setting the grading standards the attempt has been made to be conservative, in order to avoid unnecessary recommendations for phosphate fertilization. However, the evidence now points strongly in the direction of an increase in the limits of the deficient range on those soils in which the phosphate content in the 20/1 ratio extract is practically as great or greater than that in the 5/1 ratio extract.

Considering only the soils of Colorado, Wyoming and western Nebraska, the following grading scheme is highly satisfactory.

Type A Soils - Soils which yield extracts at 5/1 ratio of definitely higher phosphate concentration than is present in the 20/1 ratio extracts.

Deficient soils show 0.5 (or less) p.p.m. of P in the 20/1 ratio extract.

If the 20/1 ratio extract contains between 0.5 and 0.8 p.p.m. of P, the soil is classed as doubtful.

Soils containing sufficient phosphate yield extracts containing 0.8 (or more) p.p.m of P at the 20/1 ratio.

Type B Soils - Soils which yield extracts at the 20/1 ratio containing practically as much or more phosphate than is present in the 5/1 ratio extracts.

Soils which yield extracts at the 20/1 ratio containing definitely higher phosphate concentration than do their 5/1 ratio extracts, regardless of absolute value of P content, and

Soils which yield extracts at both 5/1 and 20/1 ratios of practically equal P content, neither extract containing more than 1.5 p.p.m. of P, are classed as deficient.

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[1] Univ. Ariz. Tech. Bull. No. 35 - October 15, 1931.

All other soils showing practically equal content of phosphate in both extracts are likely to respond to phosphate treatment and are classed as doubtful.

If one is to judge a method for determination of available phosphate by its ability to predict response to phosphate fertilization, he must find all methods proposed to date as failures, including field trials. The subject of response was discussed in the report on phosphate field trials made before this Society at Fort Collins in February 1939. Only a brief review will be given here.

Soils of Type A in which the 5/1 ratio extract contains more than 50% higher P concentration than does the 20/1 ratio extract are not likely to respond regardless of deficiency. These soils almost always require manure to produce good crops and since the soils have relatively little phosphate fixing capacity, the phosphate content of the manure can be depended on to supply the phosphate deficiency.

Very heavy soils yielding extracts of very low phosphate content at both 5/1 and 20/1 ratios are liable to show no response, because of capacity of the soil for reversion of added phosphate. Such soils can generally be identified by a high test for phosphate soluble in K_2CO_3 solution. As use of fertilizer drills which place the phosphate close to the seed becomes more common, response is expected to become more common on these soils.

Best response is to be found on the silt loam and clay loam soils, fairly high in $CaCO_3$, belonging to Type B.

A completely satisfactory explanation has not been offered for failure to get response on many carelessly farmed and non-rotated deficient testing fields. Deficiency is shown by too many methods to permit one to conclude that failure of these soils to respond means no deficiency of phosphate.

The evidence favors the acceptance of the principle of phosphate feeding efficiency. That is - on many good soils, generally of Type A, the plant obtains its phosphate requirements at a lower level of available phosphate than it is able to do on another soil giving similar test. When the soil is known to be a high yielder in spite of low phosphate test, there is no object in applying phosphate except to prevent depletion. Soils 4 and 6 in Table I gave similar tests. No. 4 is high yielding soil of a type noted for high quality, and does not respond to phosphate. No. 6 is not of a type equal to No. 4, and it produced excellent response. Well farmed soils of not high quality originally have been made to produce high yields and these soils of Type B phosphate test have shown even greater yield by phosphate fertilization.

We are satisfied that the acetate buffer extraction gives us a satisfactory measure of the level of available phosphate in the sample analyzed. The method fails to tell us how various factors will interact to change the level of available phosphate in the field during the growing season. Studies of this subject are being continued and it is hoped that a satisfactory basis for prediction of changes in available phosphate during the growing season may eventually be worked out. Today it appears that the safest practice is to sample the soil about August 1st and use the results on this sample as a guide for fertilizer treatment for the following season.

Standards for grading the Arizona soils have been set up using results of Neubauer tests on 12 representative soils of wide phosphate range as a guide. The results were so compatible among themselves that little difficulty was experienced in setting up standards. The present grading standards are:

All soils are classed as deficient which yield extracts at the 5/1 and 20/1 ratios either one of which contains less than 2.6 p.p.m. of P. Sufficient testing soils yield extracts both of which contain 4.0 (or more) p.p.m. of P. Soils giving intermediate tests are classed as doubtful. It is hoped that results of field trials may be available at some time to enable us to judge our standards, since Neubauer tests alone cannot be considered final.

TABLE I

RELATION OF EXTRACTABLE PHOSPHATE TO AVAILABLE PHOSPHATE
NORTHERN COLORADO AND WESTERN NEBRASKA SOILS

Soil No.	1		2		3		4	
Lab. No.	L-26		4435		4292		5851	
Soil Quality	Very fertile		Fertile		Poor		Fertile	
P_2O_5 by Field Trials	-		-		-		None	
Neubauer Test - Mg.P_2O_5/100 g.Soil	-		-		15.1		-	
Extractable Phosphate - Medium	Buffer	Water	Buffer	Water	Buffer	Water	Buffer	Water
Extraction Ratio:	Parts per Million of P in Extract							
1/2				0.10				
1/1		1.1						0.13
5/1	2.7	1.7	1.5		7.0		0.9	
10/1								0.18
20/1	1.8	0.95	0.8	0.25	3.5		0.6	0.14
50/1		0.50			1.6			

Soil No.	5		6		7		8	
Lab. No.	5858		4873		4877		4324	
Soil Quality	Fertile		Fair		Fair		Poor	
P_2O_5 by Field Trials	Slight Deficiency		Deficient		Deficient		-	
Neubauer Test- Mg.P_2O_5/100 g.Soil	-		-		-		1.4	
Extractable Phosphate - Medium	Buffer	Water	Buffer	Water	Buffer	Water	Buffer	Water
Extraction Ratio:	Parts per Million of P in Extract							
1/2								
1/1		0.13	0.5		0.4			
5/1	0.7		0.7		0.6		0.3	
10/1		0.11						
20/1	0.6	0.12	0.5		0.4		0.2	
50/1			0.4		0.2		0.1	

TABLE II

RELATION OF EXTRACTABLE PHOSPHATE TO AVAILABLE PHOSPHATE

WYOMING SOILS

Soil No.	1		2		3		4	
Lab. No.	5650-B		4248		4244		4246	
Soil Quality	Good		Good		Fair		Good	
P_2O_5 by Field Trials	-		-		-		-	
Neubauer Test - Mg. P_2O_5/100 g. Soil	-		5.1		4.9		3.6	
Extractable Phosphate - Medium	Buffer	Water	Buffer	Water	Buffer	Water	Buffer	Water
Extraction Ratio:	Parts per Million of P in Extract							
1/2								
1/1		0.23						
5/1	2.5		1.5		1.4		1.2	
10/1		0.25						
20/1	1.8	0.15	1.4		1.6		1.4	
50/1			0.8		1.0		0.9	

Soil No.	5		6		7		8	
Lab. No.	3572		4241		4242		0-6	
Soil Quality	Fair		Good		Good		Poor	
P_2O_5 by Field Trials	Deficient		-		-		-	
Neubauer Test - Mg. P_2O_5/100 g. Soil	3.0		2.2		1.1		-	
Extractable Phosphate - Medium	Buffer	Water	Buffer	Water	Buffer	Water	Buffer	Water
Extraction Ratio:	Parts per Million of P in Extract							
1/2								0.12
1/1								0.16
5/1	1.6		0.8		0.6		1.1	0.18
10/1					1.3			
20/1	1.5		1.8		1.8		2.5	0.13
50/1			1.3		1.4			

TABLE III

RELATION OF EXTRACTABLE PHOSPHATE TO AVAILABLE PHOSPHATE

SALT RIVER VALLEY (ARIZONA) SOILS

Soil No.	1		2		3		4	
Lab. No.	5875		5878		5874		5881	
Soil Quality	Excellent		Good		Poor		Poor	
P_2O_5 by Field Trials	-		-		-		-	
Neubauer Test - Mg. P_2O_5/100 g. Soil	10.5		6.9		5.5		3.1	
Extractable Phosphate - Medium	Buffer	Water	Buffer	Water	Buffer	Water	Buffer	Water
Extraction Ratio:	Parts per Million of P. in Extract							
1/2		2.8				0.24		0.05
1/1				0.40				0.07
5/1	15.0	1.9	4.3	0.85	6.0	0.44	1.5	0.25
10/1								
20/1	6.8	0.8	5.0	0.43	3.8	0.27	2.9	0.18
50/1								

Soil No.	5		6		7		8	
Lab. No.	5886		5884		5586		5609 (Calif.)	
Soil Quality	Poor		Poor		Good		-	
P_2O_5 by Field Trials	-		-		-		Deficient	
Neubauer Test - Mg. P_2O_5/100 g. Soil	1.3		0.9		-		-	
Extractable Phosphate - Medium	Buffer	Water	Buffer	Water	Buffer	Water	Buffer	Water
Extraction Ratio:	Parts per Million of P. Extract							
1/2								
1/1								
5/1	2.0	0.02	0.7	0.50	1.25		0.4	
10/1								
20/1	1.6	0.02	1.8	0.18	1.25		0.55	
50/1					1.2		0.7	