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Soil Reaction and Availability of Plant Nutrients

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SOIL REACTION AND AVAILABILITY OF PLANT NUTRIENTS

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When soils are strongly acid, they are usually low in available phosphorus, and they may also be poorly supplied with other elements necessary for best plant growth. This bulletin reports the results of chemical tests of several thousand samples of soil to observe the effect of soil reaction (acidity or alkalinity) on the availability of plant nutrients. It also contains information about the effect of soil acidity on the availability of nitrogen, phosphorus and sulfur in soil organic matter.

As soil acidity increases, mineral phosphates are slowly changed from forms readily absorbed by plant roots into relatively insoluble forms. At the same time, calcium, potassium and magnesium are removed from the soil by leaching. The degree of soil deterioration, and therefore the need for treatment with lime and/or fertilizer, can be determined by chemical tests for acidity and for the availability of mineral plant nutrients.*

AVAILABILITY OF MINERAL PHOSPHATES

Data on the pH value and easily soluble phosphorus of 3,297 surface soils are given in Table I. These soils were classified into five groups according to probable response to fertilizer treatment as shown by previous field tests.** The results show that the percentage of soils low to very low in available phosphorus declined rapidly at somewhere about pH 6.0 to 6.3† The percentage of soils very high in available phosphorus increased rapidly above pH 6.7. The number of soils containing a medium quantity of easily soluble phosphorus was relatively constant throughout the entire range of pH values studied.

* Crop yields on acid soils may be reduced by toxic forms of soil organic matter and by harmful concentrations of aluminum salts.

** See Okla. Agri. Exp. Sta. Bul. B-205, *Easily Soluble Phosphorus in Oklahoma Soils*, page 7.

† pH is a measure of acidity or alkalinity. Neutral soils, neither acid nor alkaline, will have a pH of around 6.7 to 7.3. Strongly acid soils have a pH of 5.5 or less, and strongly alkaline ones 8.5 or more.

*Although there was a general tendency for soils to be low in easily soluble phosphorus when strongly acid, and high when neutral or alkaline, a soil test is the only accurate method of determining the relative solubility of inorganic phosphorus in a specific sample.**

AVAILABILITY OF ORGANIC PHOSPHORUS, NITROGEN AND SULFUR

Phosphorus.—About one-third of the total phosphorus in the surface soil occurs in the form of organic phosphates. Some of the organic phosphorus in a soil** will be changed to an inorganic form during summer periods when soil conditions are favorable for the growth of soil organisms. Therefore, crops which grow and mature during the summer months frequently do not benefit from phosphate fertilization on acid soils low in easily soluble mineral phosphate but high in organic matter. Plants which grow during warm weather obtain more phosphorus from the decomposition of organic residues than is obtained by plants which grow during the spring or fall.

After acid soils containing an abundance of organic matter under virgin conditions are farmed for a period of years, crop yields gradually decrease as the organic matter declines. Then a profitable response from phosphate fertilizers will be obtained when crops having a high phosphorus requirement and a relatively high tolerance to soil acidity are grown.

Nitrogen and Sulfur.—Nearly all of the nitrogen and sulfur in the average soil occurs in the soil organic matter. These elements are changed to available forms (nitrates and sulfates) when soil organic matter is decomposed by soil organisms. Since many soil organisms are not as active in acid soil as in soil containing a good supply of lime, the rate at which nitrogen

* The occurrence of neutral or slightly acid soils which are low in easily soluble phosphorus can probably be explained by their geologic origin. Many Oklahoma soils developed on non-acid parent material, low in easily soluble phosphorus. Chemical weathering during previous geologic periods changed inorganic phosphorus compounds to relatively insoluble forms. The exposure of the acid soil residues low in easily soluble phosphorus to bicarbonate or other alkaline solutions during the process of geologic erosion and subsequent formation of sedimentary rock neutralized any acidity present, but it did not change the insoluble phosphate in these sediments to readily available forms. The appearance of these sedimentary rocks at the surface of the earth in regions of low rainfall where limited chemical weathering has occurred would be responsible for the development of a neutral or slightly acid soil which is low in easily soluble phosphorus.

** Bower has shown that iron phytate is decomposed very slowly. *Soil Science* 59: 277-286 (1945).

*Table I. A comparison of soil pH value and quantity of easily soluble phosphorus.**

pH value of soil	Total number of soils analyzed	Number of soils in different easily soluble phosphorus groups**					Percentage of soils in different easily soluble phosphorus groups				
		Very Low	Low	Medium	High	Very High	Very Low	Low	Medium	High	Very High
4.9	18	11	4	2	1	0	61.1	22.2	11.1	5.6	0.0
5.0	12	7	1	3	1	0	58.4	8.3	25.0	8.3	0.0
5.1	23	9	8	3	2	1	39.1	34.8	13.0	8.7	4.4
5.2	22	15	4	0	2	1	68.2	18.2	0.0	9.1	4.5
5.3	30	15	9	4	2	0	50.0	30.0	13.3	6.7	0.0
5.4	51	24	16	3	6	2	47.1	31.4	5.9	11.7	3.9
5.5	68	25	21	15	5	2	36.8	30.9	22.1	7.3	2.9
5.6	69	26	17	7	8	1	52.2	24.6	10.2	11.6	1.4
5.7	97	36	37	17	5	2	37.1	38.1	17.5	5.2	2.1
5.8	93	36	30	15	9	3	38.7	32.3	16.1	9.7	3.2
5.9	88	33	34	6	13	2	37.5	38.6	6.8	14.8	2.3
6.0	100	28	32	16	16	8	29.0	32.0	16.0	16.0	8.0
6.1	122	32	35	16	19	20	26.2	28.7	13.1	15.6	16.4
6.2	94	28	21	18	15	12	29.8	22.3	19.1	16.0	12.8
6.3	106	36	18	16	19	17	34.0	17.0	15.1	17.9	16.0
6.4	100	19	19	22	16	24	19.0	19.0	22.0	16.0	24.0
6.5	128	25	25	21	30	27	19.5	19.5	16.5	23.4	21.1
6.6	93	14	26	17	16	20	15.0	28.0	18.3	17.2	21.5
6.7	138	29	29	25	30	25	21.0	21.0	18.1	21.8	18.1
6.8	99	10	17	16	21	35	10.1	17.2	16.3	21.2	35.3
6.9	103	11	21	9	25	37	10.7	20.4	8.7	24.3	35.9
7.0	120	16	18	21	25	40	13.3	15.0	17.5	20.8	33.4
7.1	125	11	16	17	27	54	8.8	12.8	13.6	21.6	43.2
7.2	118	9	16	14	28	51	7.6	13.6	11.9	23.7	43.2
7.3	117	9	11	13	26	58	7.7	9.4	11.1	22.2	49.6
7.4	111	10	15	18	17	51	9.0	13.5	16.2	15.3	46.0
7.5	105	8	14	15	12	54	7.8	13.6	14.6	11.6	52.4
7.6	100	7	10	9	20	54	7.0	10.0	9.0	20.0	54.0

Table I (continued)

pH value of soil	Total number of soils analyzed	Number of soils in different easily soluble phosphorus groups**					Percentage of soils in different easily soluble phosphorus groups				
		Very Low	Low	Medium	High	Very High	Very Low	Low	Medium	High	Very High
7.7	96	4	14	8	15	55	4.2	14.6	8.3	15.6	57.3
7.8	114	3	6	15	27	63	2.6	5.3	13.2	23.7	55.2
7.9	92	4	7	6	21	54	4.4	7.6	6.5	22.8	58.7
8.0	81	7	5	4	13	52	8.6	6.2	4.9	16.1	64.2
8.1	92	6	4	5	12	65	6.5	4.4	5.4	13.0	70.7
8.2	77	3	3	3	16	52	3.9	3.9	3.9	20.8	67.5
8.3	85	5	0	4	11	65	5.9	0.0	4.7	12.9	76.5
8.4	69	3	6	4	9	47	4.4	8.7	5.8	13.0	68.1
8.5	54	2	4	6	5	37	3.7	7.4	11.1	9.3	68.5
8.6	37	0	1	2	7	27	0.0	2.7	5.4	18.9	73.0
8.7	19	3	1	3	4	8	15.8	5.3	15.8	21.0	42.1
8.8	8	0	0	1	1	6	0.0	0.0	12.5	12.5	75.0
8.9	7	0	0	0	1	6	0.0	0.0	0.0	14.3	85.7
Total 3279											

*Determined by extraction with fifth normal sulfuric acid.

** Very low=0-7 p.p.m., Low=8-15 p.p.m., Medium=16-25 p.p.m., High=26-50 p.p.m., Very High=51 plus p.p.m., of easily soluble phosphorus. Probable fertilizer response within each group was determined from results of earlier tests. See Okla. Agri. Exp. Sta. Bul. 205.

and sulfur are liberated from organic material decreases as acidity increases. The rate of liberation may not meet plant requirements when temperatures are unfavorable for the growth of soil bacteria.

Adding limestone to an acid soil frequently produces a large increase in yield of small grain in years when the early spring is wet and cool. This is due to a more rapid growth of soil bacteria on the limed soil.

AVAILABILITY OF BASIC ELEMENTS

The quantity of easily soluble calcium, magnesium and potassium in a soil gradually declines as acidity increases, *but the amount of these elements available for plant growth in different soils is not determined by the degree of acidity.* Instead, the amount available for plants depends upon the base exchange capacity of the soil.* Strongly acid soils contain a considerable quantity (40% or more) of basic elements in the exchange complex; consequently, a strongly acid clay soil may have more exchangable bases in it than a neutral sandy loam.

Calcium

Table II shows the soil reaction and exchangeable calcium in 3,475 samples of soil collected from different areas in Oklahoma. Since these samples were not classified according to texture, it is not easy to make an accurate interpretation of the results. However, a large majority of the soils which were very high in replaceable calcium were alkaline in reaction. As the acidity increased, the number of soils containing an abundant supply of available calcium decreased. However, a few alkaline soils were very low in available calcium, and a considerable number of strongly acid soils were high to very high in available calcium.

A good calcium supply in an acid soil may be quite significant because acid-tolerant plants can obtain enough of this element for optimum growth without an application of lime. Tests for available calcium are more important than a test for soil acidity when acid tolerant crops are planted.**

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* Insoluble organic acids and acid alumino silicates are capable of absorbing and releasing basic elements such as calcium, potassium and magnesium. These compounds, because of a large surface exposed to the soil moisture, determine to a very great extent the rate at which the root hairs can obtain nutrients from the soil.

** Acid-tolerant crops commonly grown in Oklahoma are listed in Okla. Agri. Exp. Sta. Bul. B-316, *Crop Adaptation to Soils of Varying Acidity or Alkalinity.*

Table II. A comparison of soil reaction and the quantity of exchangeable calcium.***

Soil Reaction	Content of Exchangeable Calcium					Total No. of Samples	Exchangeable calcium calculated in percent of each group				
	V. Low	Low	Med.	High	V. High		V. Low	Low	Med.	High	V. High
Basic†	21	37	251	271	810	1390	1.5	2.7	18.0	19.5	58.3
Neutral	29	40	144	97	62	372	7.8	10.7	38.7	26.1	16.7
Slightly Acid	23	55	222	100	72	472	4.9	11.7	47.0	21.2	15.2
Moderately Acid	36	63	245	93	48	485	7.4	13.0	50.5	19.2	9.9
Strongly Acid	96	120	403	88	49	756	12.7	15.9	53.3	11.6	6.5
					Total	3475					

* Obtained by electrometric or colorimetric measurement of hydrogen ion concentration.

** Determined by extraction with sodium acetate solution buffered to pH 4.8 with acetic acid. Conn. Agri. Exp. Sta. Bul. 450, p. 592.

† Degree of alkalinity not determined.

Table III. A comparison of soil reaction and exchangeable magnesium.***

Soil Reaction	Content of Exchangeable Magnesium					Total No. of Samples	Exchangeable Magnesium calculated in percent of each group				
	V. Low	Low	Med.	High	V. High		V. Low	Low	Med.	High	V. High
Basic†	0	13	44	188	1150	1395	0.0	.9	3.2	13.5	82.4
Neutral	0	6	30	46	292	374	0.0	1.6	8.0	12.3	78.1
Slightly Acid	0	2	35	64	371	472	0.0	.4	7.4	13.6	78.6
Moderately Acid	0	17	35	58	373	483	0.0	3.5	7.3	12.0	77.2
Strongly Acid	1	51	99	88	518	757	.1	6.8	13.1	11.6	68.4
					Total	3481					

* Obtained by electrometric or colorimetric measurement of hydrogen ion concentration.

** Determined by extraction with sodium acetate solution buffered to pH 4.8 with acetic acid. Conn. Agri. Exp. Sta. Bul. 450, p. 592.

† Degree of alkalinity not determined.

Occasionally a neutral or alkaline soil may be low in available calcium and may need an application of limestone to provide an adequate supply of calcium for optimum plant development.

Magnesium

The availability of magnesium in 3,481 samples of soil collected from different parts of Oklahoma is given in Table III. Only one soil was very low in exchangeable magnesium. Many of the strongly acid soils were high to very high in this element. No relation was found between high acidity and low availability of magnesium.

Preliminary soil fertility tests in Oklahoma indicate that magnesium may be deficient in strongly acid sandy soils which have a strongly acid sandy subsoil. According to the results in Table III an occasional magnesium deficiency may be found in soils which are not strongly acid. It is quite probable that a soil deficient in magnesium would also be deficient in calcium, phosphorus and potassium. Such soils would be recognized as unproductive soils, but the fertilizer requirements could not be determined accurately unless chemical tests or extensive field studies were made.

Potassium

Results of studies on the availability of potassium are somewhat similar to data obtained for calcium. When the quantity of reserve potassium in a soil is high it is constantly moving from the reserve supply into the available form. Plants which do not have a high requirement for potassium continue to obtain potassium from the soil throughout the growing season. Strongly acid sandy soils with strongly acid sandy subsoils are usually deficient in available potassium. Many subsoils in Oklahoma are not acid and contain more clay than the acid surface soils. When soluble potassium salts are carried into the subsoil during periods of abundant rainfall, a high percentage of the potassium remains in the soil profile because it replaces calcium in the exchange complex and the resulting calcium salt is lost in the drainage water.

Many surface soils which are deficient in replaceable potassium do not respond to potash fertilization when deep rooted crops are grown because these crops obtain a sufficient quantity of potassium from the subsurface soil to supply plant requirements.

Potash deficiency may be observed on sandy alluvium originating from rocks deficient in potash. Consequently, the absence of soil acidity may not always indicate an adequate potassium supply for maximum crop production. Non-acid soil derived from the weathering of basic igneous rocks is frequently deficient in available potassium.

SUMMARY

The availability of inorganic phosphorus declines with increasing soil acidity under average conditions. Over three thousand samples of Oklahoma soil were classified according to pH value and available phosphorus content. There was a rapid increase in the percentage of soils which were low to very low in available phosphorus as their pH value declined below 6.2.*

Non-acid soils may be low in available phosphorus when very little total or available phosphorus is present in the weathered material on which the soil developed.

The availability of organic phosphorus, nitrogen and sulfur for plant growth will be reduced as the acidity of a soil increases, because an acid condition is less favorable for the growth of soil bacteria which decompose soil organic matter.

The available calcium content of Oklahoma soils decreased as the acidity increased. More calcium was present in fine textured soils than in sandy soils having the same intensity of acidity (pH value). When acid tolerant plants are grown, information concerning the supply of available calcium in the soil is more important than data on acidity in determining the need for lime.

The availability of magnesium was nearly as high in the strongly acid group of soils as in the non-acid soils. Only a very small percentage of the soils tested were low to very low in available magnesium.

Available potassium was usually low in strongly acid sandy soils. The clay content of the soil was more important than intensity of acidity in determining the quantity of replaceable potassium in medium and fine textured soils.

* This pH is the approximate dividing line between slightly acid soils and moderately acid soils. The percentage of soils which were very high in available phosphorus increased rapidly above pH 6.7. This pH value separates slightly acid soils from neutral soils.

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