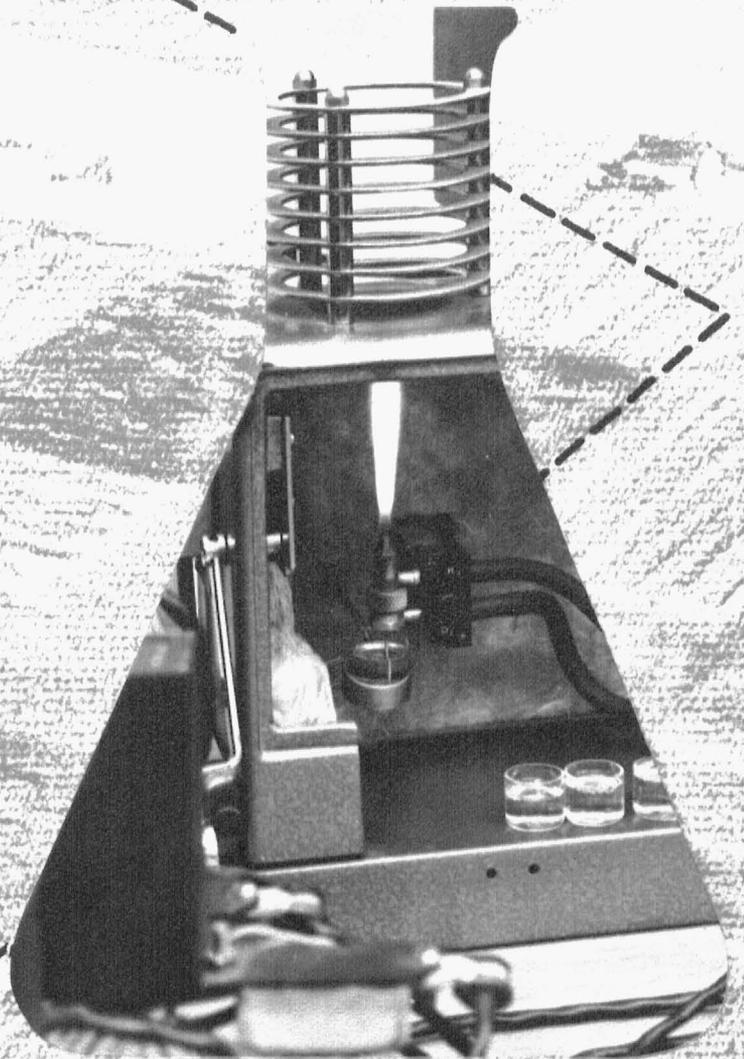


An Explanation of Theory and Methods of

SOIL TESTING



Flame Photometer

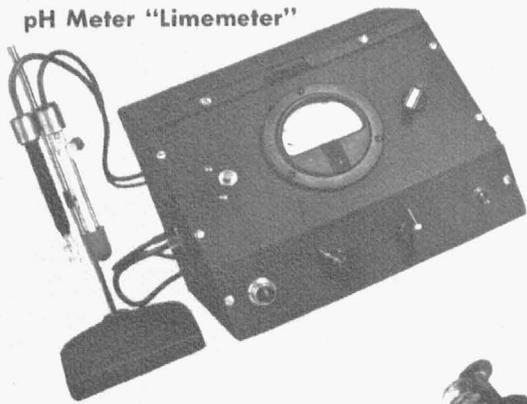
E. R. GRAHAM

University of Missouri Agricultural Experiment Station

Bulletin 734

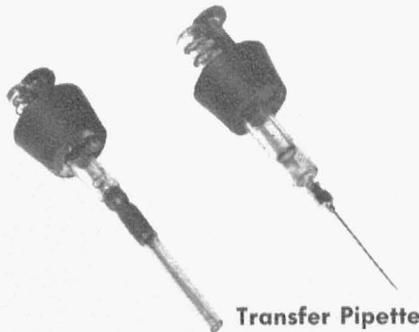
July, 1959

pH Meter "Limemeter"



FOREWORD

Intensive cultivation of the soil for larger crop yields through modern technology has been the farmer's home-spun relief from the increasing economic pressure. Since he could not pass on the increasing costs to anyone else, he has been expending more of his original productive assets. Moreover, he has been "throwing in" more *soil fertility* with the increased sales. As a consequence our soils are being rapidly mined of this natural resource—our basic food security. Even though we may be failing in our economic procedures to recognize the depreciation of the soil and to make allowances therefor in tax assessments, the soil fertility is presenting its own evidence of decline through the lowered crop quality and the numerous farms "worn out" and sold for taxes in a single generation.



Transfer Pipette

Chemical tests of the soil are one of the first means of taking inventory of the productive assets of agriculture. They measure land in terms of new dimensions. These are not acres. They are the reserves of plant nutrients in kinds and amounts of essential chemical elements. These, in turn, indicate the soil's capacity to produce feed and food—when favored by the weather. Through soil tests, the Missouri farmers are estimating the present levels of productivity in their soils. Such tests also give farmers—and the rest of us—a growing apprehension of the speed with which our soils are being exhausted.

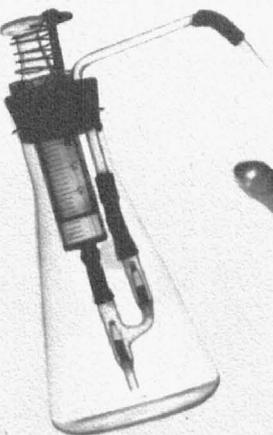
Soil testing has moved from the single center at the Experiment Station to the many county agent laboratories and thence out to the farmers' own fields. Reports of such tests of field samples are no longer shunned as technical strangers. They have become welcome contributors to the family council. They bring more nutritious food to the family table, greater security to country life.

These tests encourage the farmer to watch more closely for irregularities in the growth and health of plants and in the health and reproduction of his livestock. Such failures point to short feeding due to deficiencies in soil fertility.

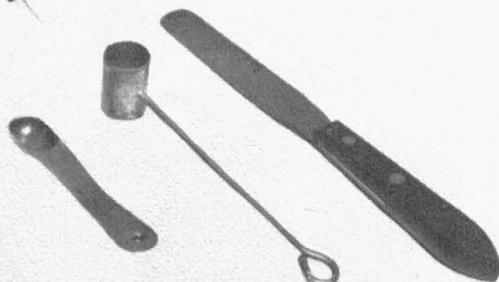
As a consequence of this better understanding of our problems through soil tests, we minister to the soil at the point where the problems originate—to prevent rather than await the resultant ills and attempt to cure them. Thus, wisely aimed, our increasing efforts toward soil building are actually raising the soil fertility levels.

By these well-informed activities, the entire farming business and all that emanates from it are lifted correspondingly higher. Test-guided ministrations in the form of soil treatments, like lime and other fertilizers already used over much of Missouri, are bringing agricultural betterment from the ground up.

WM. A. ALBRECHT



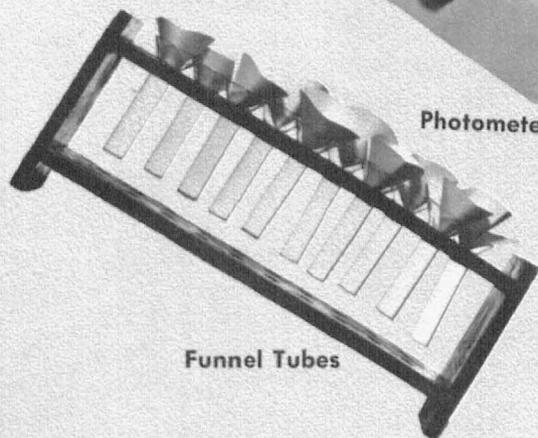
Pipette "Smith Automatic"



Measuring Spoons



Photometer "Spectronic 20"



Funnel Tubes

SELECTION of the kind and amount of fertility treatment depends (1) on the crop's nutrient requirements and (2) on the ability of a given soil to supply those nutrients.

In 1813 Sir Humphrey Davy stated that if a soil is unproductive, the cause of its sterility can be easily determined by chemical analysis. In many instances this has been true. In others, methods have often been time-consuming and their results difficult to interpret into the biological activity of growing plants.

Considerable progress has been made in developing methods that are rapid and accurate enough for practical purposes. But remember that in a diagnosis of the needs of plants, all factors involved in plant growth need to be considered and a proper interpretation must be made of the assembled facts.

This publication describes the reasoning by which chemical soil-test measurements are converted into suggested amounts of lime and other fertilizer treatments. The reactions of chemical reagents used in making soil tests are also described. It is hoped that this discussion will be especially helpful to county agents and others who must understand and interpret soil tests.

A great many factors of the soil determine its productivity. This bulletin does not consider all of the various tests for them, or compare one test with another. Rather, its objective is to report the tests now used in Missouri which have given most satisfactory results. In some instances improvements are anticipated in both the chemical procedures and the field correlations. Once demonstrated, these will be worked into this system.

The chemical tests now in use help to measure the following factors that enter into the productivity of soil: 1. *Organic matter (percent by weight)*. 2. *Extractable phosphorus (by Bray's extracting solutions, strong and weak)*. 3. *pH in water (glass electrode)*. 4. *pH in salt solution*. 5. *Exchangeable hydrogen*. 6. *Exchangeable potassium*. 7. *Exchangeable magnesium*. 8. *Exchangeable calcium*.

While these eight are not all the soil factors in control of productivity, they are the major fertility items which lend themselves to reliable measurement. They are also sufficient to give a fairly clear picture of the part the soil and its chemical activities play in crop production.

These eight tests reveal information about the nature of the soil colloid with respect to its percentages of saturation by the major nutrient cations and the non-nutrient hydrogen. Thus they furnish ratios of the amounts of exchangeable potassium, magnesium, and calcium on the surface of the colloidal particle which can modify the chemical composition of plants. The tests also reveal the fertility level of phosphorus and the amount of organic matter present.

by

Ellis R. Graham

*An Explanation of
Theory and Methods
of*

SOIL TESTING

the COLLOIDAL COMPLEX

The soil colloid consists of organic matter, or humus, and clay. The many reactions and interactions of these components are the major center of the fertility supply and of nutrient ion activities that deliver nutrients to plants. Soil tests reach into the soil to interpret the nature of the colloid; they bring out a better understanding of how the soil can feed the plant a well-balanced ration.

To use and understand soil testing under Midwest conditions, we need to understand the importance of the colloidal complex. Soil colloids are composed principally of inorganic material but highly decomposed organic matter also has colloidal properties, as shown by many soils. These tiny particles of mineral clay and humus have certain physico-chemical properties which are of decided importance. Such fundamental properties as plasticity, aggregation, and the many adsorption-exchange reactions by ions on the surface of colloidal particles are conditioned by the colloidal complex.

These properties are illustrated by the soil being readily molded when wet; by its formation of granular structure in proper moisture; its capacity to filter many chemical ions out of solutions; and, conversely, to put into a solution going through the soil many other chemical ions in exchange. It is through this process of adsorption and exchange that the colloid can be stocked with fertility through soil treatments. The plants exchange hydrogen for the nutrient elements they need as their roots make contact with colloidal surfaces.

For a given unit of mass, the humus colloids are more active than the clay colloids. But since so many of our soils have a low humus content—which is becoming even lower through cropping and erosion—the clay fraction is the more important.

There are many minerals making up the different types of clay. These clays exhibit different colloidal properties but all of them can adsorb and exchange ions. Clays also vary greatly in their hydration or water-combining properties, their total adsorptive capacities, and the amounts and kinds of ions they adsorb.

The possibilities for variation in soils due to (a) different kinds of clay, (b) different amounts of clay, and (c) different humus contents in soils are almost limitless. This brings corresponding possibilities for great variation in ion exchange capacity, in the supply of plant nutrients in store, and in the other physico-chemical characteristics of the soil.

Soils containing much sand but little organic matter, or a clay of the Kaolin* type, have a low ion exchange capacity. They neither swell nor shrink much. They are tilled easily. Soils with a low sand content, a moderate organic matter content, and a clay of the montmorillonitic** type have a high exchange capacity. They usually swell and shrink considerably. They are difficult to till.

The physico-chemical properties of soils lend themselves to modifications through cropping and treatments. A discussion of some of the modifications and characteristics follows.

SALTS in SOIL SOLUTION

All soil systems contain some salt dissolved in the soil water. But we dare not consider this system the same as a nutrient solution culture commonly used in laboratory demonstrations of plant growth. These two systems differ in (a) that the soil water contains less salt in most instances than the nutrient solution; and (b) that once the plant adsorbs an ion from this soil-water solution an ion is replaced by a similar one from the soil colloid.

The soil water is a dynamic solution which contains at least a trace of every plant nutrient. Nutrients ionized in the water are usually referred to as the active ions; those adsorbed and held on the colloidal surface for exchange are called reserve ions. In most instances, the ions held either by adsorption on the colloid surface or as active ones in its surrounding film of water can be considered available to the plant.

One apparent weakness of present soil testing procedures is their failure to give information about the active anions, especially about sulfate, nitrate,

*Kaolin: The minerals of this group are characterized by a composition approximating the chemical formula $\text{Al}_2\text{O}_3 - 2\text{SiO}_2 - 2\text{H}_2\text{O}$.

**Montmorillonite: The minerals of this group have an approximate chemical formula of $4\text{SiO}_2 - \text{Al}_2\text{O}_3 (1 + x) \text{H}_2\text{O}$.

physiological transformations.

In case the crop is allowed to return to the soil, the elements in the plant go back to the soil colloids for another cycle.

In the more common case, where crops are removed, this addition of organic matter does not take place. This secondary assembly line of crop production, so active in the virgin cycle from soil to plant and plant to soil, is broken.

Another fertility flow of great importance is associated with the weathering of soil minerals. The silt and sand separates of soils which contain weatherable minerals will, when encouraged by organic matter and clay, transfer ions from the crystal of these minerals to the surface of the colloidal complex.¹ In cases where the sand, silt, and clay of the soil are composed of only quartz, devoid of nutrient ele-

ments, or consist of other extremely resistant minerals, the supply of nutrient ions on the colloid is not restored by "resting of the soil." It can be maintained only by addition of nutrient elements such as fertilizers, manures and plant residues.

The basic concept of plant nutrition by root hair-colloid contact assumes that: (a) the roots must sample the soil colloid system; (b) the nutrient ions are strongly adsorbed in this colloid system; and (c) the nutrient ions do not move to the plant except by exchange for some other ions. Figure 1 visualizes the exchange of hydrogen for calcium, magnesium, potassium, manganese, copper, cobalt, iron, and other cations.

Nitrogen and phosphorus, according to present concepts, must be considered as special cases. These will be discussed later.

ACCURACY of Sampling Methods

It is apparent to workers in the field of soils that no single soil sample can be a perfect reflection of the fertility level of an area of soil. Therefore, in soil testing there are two major sources of error, (a) those associated with the sampling of the soil and (b) those associated with the routine chemical analyses. The errors in the chemical analyses are relatively small. They are less than 5 percent in most tests and seldom more than 10 percent. But the error in sampling the soil area may frequently be 100 percent or more, depending on the past soil treatments of the field.

Effects of Past Treatments

Fields which have received little or no treatment reveal a soil which is rather uniform and one which is subject to little error in sampling. This includes fields that have been treated frequently, but with only small amounts.

A good example of a uniform soil is plot number 38 on the Sanborn experimental field at Columbia. The test results of a set of samples from this plot are in Table 1.

Another plot, number 2, on Sanborn field shows a heterogeneity or variation of soil brought about by a single heavy soil treatment. See Table 2.

A single composite sample of soil from plot 38 reflects the fertility level of the soil with a degree of accuracy suitable for most management problems. The samples of plot 2 show that the phosphorus has not been mixed well with the soil, and that the

lime treatment was not heavy enough or mixed well enough. A single sample from plot number 2 would be much less likely to reflect the average fertility level of the soil than would one from plot 38.

Sampling Untreated or Moderately Treated Fields

Experience indicates that a number of borings of the 0-7 inch soil horizon, mixed to make one sample for each soil type in the field, generally gives data sufficiently accurate of that field for most soil management practices. A final sample consisting of five to ten of the composites of cores per 40 acres is suggested.

The size of the field concerned has had no effect on the magnitude of the sampling error. Such items as crop residues, degree of erosion, and varia-

Methods of sampling moderately treated fields.

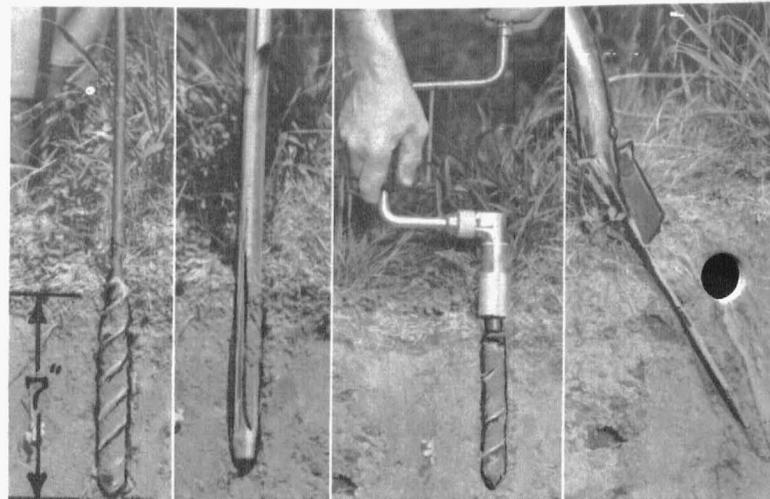


TABLE 1
SOIL TEST DATA FROM PLOT 38*, SANBORN FIELD, SHOWING THE HOMOGENEITY OF THE SOIL

Organic Matter %	Phosphorus Lbs/A		Potassium Lbs/A	Magnesium Lbs/A	Calcium Lbs/A	Hydrogen ME/100 gm	pH Soil in Water
	P	P ₂ O ₅					
2.5	31	72	158	180	6000	1.0	6.8
2.6	25	59	208	260	5500	2.0	6.5
2.7	27	62	168	230	6500	1.0	6.9
2.1	19	44	224	350	6500	1.0	6.9
2.2	20	47	180	270	6500	1.5	6.5
2.4	36	83	156	230	6000	2.0	6.5

* This soil had several treatments of limestone, 2 tons per acre, as needed since 1915 and also 400 pounds of fertilizer, 4-12-4, with every four years in the rotation of corn, oats, wheat and clover. The samples were taken in the spring of 1955.

TABLE 2
SOIL TEST DATA FROM PLOT 2, SANBORN FIELD, SHOWING THE HETEROGENEITY OF THE SOIL

Organic Matter %	Phosphorus Lbs/A		Potassium Lbs/A	Magnesium Lbs/A	Calcium Lbs/A	Hydrogen ME/100 gm	pH Soil in Water
	P	P ₂ O ₅					
2.9	140	326	248	780	4100	5.0	5.2
2.2	155	360	378	860	4300	3.0	5.8
2.1	61	141	280	550	1650	5.0	5.1
2.4	135	314	192	620	3000	3.5	5.5
1.8	96	224	164	1040	4900	4.0	5.9
2.0	155	360	264	170	5100	3.5	5.6

This plot had nitrogen, phosphorus and potassium equivalent of forty bushels of wheat (grain and straw removed) applied annually since 1888. In 1950 dolomitic limestone, rock phosphate, and super phosphate were applied. The samples were taken in the spring of 1955.

tion in soil type are much more important and should be considered.

Sampling Heavily Treated Fields

In this case the soil treatments have modified the fertility level so much that differences occurring because of soil type, erosion, residues returned, etc., have been largely submerged by those due to the treatments. Residues of the fertilizers are left in bands or areas probably less than 2 inches in diameter. This accents the heterogeneity or variation of the surface area.

In sampling these fields, the samples should be taken in such a manner that the heterogeneity of the soil may be studied. To do this, instead of using the core method, make a vertical cut, exposing the face of the surface soil, 7 inches in depth, and at right angles to the lines of fertilizer applications. Then take a square of soil 3 inches wide, 3 deep, and 1 inch thick and collect in a sample bag. Next, take a slice of the 3 inches just below, 3 wide and 1 thick, and put it into another sample bag. This can be labeled sample number two. Repeat this process at a location to the right of the first pair of samples to get samples number three and number four. Then move to the right again for another pair, the upper one being number five and the one below, number six.

These six samples (or you can take more by extending this order) should reveal positions where

various amounts of fertilizer have been placed. By sampling areas of maximum, low and medium concentration, this method gives a suitable inventorial picture of the field's levels to guide future management practices. With variable soils this sampling process may be repeated in as many locations as deemed necessary.

Seasonal Variation of Active Fertility

Test values of soils are subject to some seasonal variation. This is especially true for exchangeable potassium. During the summer months, the plants and micro-organisms take up a significant percentage of exchangeable potassium. The portion which is in the grain and hay removed from the land is removed from the soil. However, the amounts adsorbed by the roots, by the micro-organisms, and those remaining in the residues are returned to the exchange complex after harvest, when autumn weather comes.

Thus the lowest value for exchangeable potassium would be anticipated in the autumn, and the highest in the late winter. The same situation is probably true of all other test values of the nutrients. Values of organic matter and pH would be influenced to a much lesser degree. In general, separate fall or spring samplings need not be made to correct test values other than that of potassium. For potassium, you can increase the test value by 100 pounds per acre as a correction for samples taken in

the late summer or early fall.

Subsoil samples frequently reveal important information. Fewer of these samples are needed, however, because subsoils are not usually treated and do not become so heterogeneous.

The values represented by the soil tests for one sampling may be used for many years without re-sampling and re-testing the area. It is advisable to re-test at least once in ten years.

A common misconception is that the effects of a single treatment will show in a soil test the next year. This may or may not be the case, depending on the amount of the soil treatment and the number of samples taken. More likely, a period of four or five years will be required for the soil to come to equilibrium with its treatments, or before a more accurate idea of the soil's fertility level may be obtained by testing it.

The Nitrogen Supply

Test results reveal the organic matter content by percent of the soil's weight. This is a good place to start with your interpretation of a soil test.

The organic matter usually contains about one-twentieth, or 5 percent of nitrogen. Thus we can convert reported test figures into total nitrogen per acre. For example, suppose the organic matter content is 3 percent for the 7 inches of plowed surface soil, weighing 2,000,000 pounds per acre. This would be 60,000 pounds of organic matter, and 3,000 pounds of nitrogen per acre.

Knowing that nitrogen costs about 10 cents per pound, these figures make the farmer feel pleased with his productive assets. But we must remember that only 2 to 4 percent of the total nitrogen in the organic combination in the soil will become active and available to the plants during an average growing season.

In our example, only 60 pounds per acre (.02 x 3,000 pounds) would become "available" nitrogen. This is far short of the 200 pounds required to grow a 100-bushel crop of corn.

Soils which are deep, reveal poor drainage, have a high clay content, or consist of sands, all deviate from this 2 to 4 percent rate of nitrification, or conversion of organic nitrogen into its nitrate and "available" form. Naturally, the farmer is the first one to recognize and to appreciate these differences between organic nitrogen and active ionic nitrogen, sometimes called "mineralized" nitrogen.

The test of the soil's organic matter is, then, a measure of the stock of potential nitrogen for plant nutrition. Testing for nitrogen strikes at what is usually the major soil deficiency for better crops. It is also the buffer, when not deficient, against ir-

regularities from fertilizer additions.

Estimating Nitrogen Needs

The most important factor in determining the nitrogen need is the crop to be grown. The required elemental nitrogen varies with crops; for example:

100 bushel corn yield requires 200 pounds N

80 bushel barley yield requires 160 pounds N

40 bushel wheat yield requires 80 pounds N

1 ton timothy yield requires 25 pounds N

Once the amount of crop yield has been established, the factors influencing the soil's available nitrogen may be considered. The soil must be analyzed and examined first in terms of percent nitrogen (obtained from percent organic matter) and second in the terms of the depth to which nitrification will proceed. Table 3 is useful in arriving at the available nitrogen in a tested soil showing a certain percentage of organic matter.

Table 3 reflects differences in available nitrogen due to profile characters of soil. The past crop and its residues also modify the amount of available nitrogen. If the past crop was a legume, the available nitrogen will be increased from 30 to 60 pounds per acre. If the residues were straw or weeds, a temporary reduction of available nitrogen may be observed.

Example: Diagnosis of a Nitrogen Problem

Let us assume that enough soil nitrogen is desired to produce a 100 bushel corn yield on a silt loam with 2.5 percent organic matter and with an effective depth of top soil of 7 inches. Also assume that 1 ton of legumes was plowed under, 6 tons of manure were applied, and the soil was well supplied with lime and phosphate.

Calculations:

- (1) 2,000,000 pounds soil per acre in the top 7" x 2.5% = 50,000 pounds organic matter per acre.
- (2) Since organic matter is approximately 1/2 carbon, then $50,000 \div 2 = 25,000$ pounds carbon per acre.
- (3) Most upland soils in Missouri have a C-N ratio of 10:1, hence $25,000 \div 10$ gives 2500 pounds nitrogen per acre-seven inches of soil.
- (4) If the normal nitrogen release from decomposition of organic matter under corn is 4 percent, then $2500 \times 0.04 = 100$ pounds nitrogen made available from the organic matter in the soil.
- (5) The nitrogen added by an estimated 1 ton of legumes is 30 pounds. (Each ton of legume residue turned under is expected to release 30 pounds of nitrogen in the first year and 10 pounds in the second year.)
- (6) Nitrogen added by an estimated 6 tons of manure is 24 pounds. (Nitrogen release from manure is estimated to be 4 pounds per ton in the second year.)
- (7) A 100-bushel corn crop requires 200 pounds of nitrogen (2 pounds per bushel).
- (8) For the 200 pounds required, there are available (a) 100 pounds from the soil; (b) 30 from the legumes; (c) 24 from the manure, or a total of 154 pounds. This leaves 46 pounds to be added as fertilizer nitrogen.

The carry-over of nitrogen in dry years has become a factor worth considering in calculating the nitrogen needs. Apparently, as much as the sum of the nitrogen applied plus about one-half of the normal amount of nitrification can carry over during periods of no leaching and low crop production.

The problems of when and how to apply nitrogen, as well as the amount, are now receiving much attention. Much local variation will probably be reported. Each farm manager must study his own nitrogen problem in detail if he is to solve it wisely and economically.

TABLE 3
ESTIMATES OF AVAILABLE NITROGEN (POUNDS PER ACRE) FOR GIVEN PERCENTAGES OF ORGANIC MATTER OF DIFFERENT SOILS

Organic Matter by Test %	Sandy Bottom Land	Deep Uplands e. g. Marshall Series		Putnam Silt Loam, Shallow Soil		Heavy, Poorly Drained Soils
		Untreated	Treated* Lime & Phosphorus	Untreated	Treated Lime & Phosphorus	
0.5	30	40	55	20	40	
1.0	60	60	80	30	60	
1.5	90	80	105	40	80	20
2.0	120	100	130	50	100	25
2.5	150	120	160	60	120	30
3.0	180	140	180	70	140	35
3.5		160	200	80	160	40
4.0		180	210	90	180	45
4.5		200	230	100	200	50
5.0						

* Since the natural fertility level of deep Uplands soils such as the Marshall series is higher than shallow Uplands, and treatment of lime and phosphate would have less influence on available nitrogen than similar treatments on lower fertility soils.

THE Phosphorus SUPPLY

Such phosphorus minerals as apatite furnished the original supply of phosphorus found in soils. Biological activity soon converts some of the miner-

al phosphorus into organic phosphorus. In many of the high organic soils of the Midwest the phosphorus contained in the organic residues will repre-

sent 50-60 percent of the total soil phosphorus. The apatite type of phosphorus mineral is rapidly weathered, and this weathering, along with other processes of soil development, leads to many other forms of soil phosphorus.

Soluble phosphates are strongly sorbed by the soil; and investigations have shown that this takes place by three main mechanisms: (1) formation of insoluble precipitates containing phosphate; (2) strict absorption which follows well-established laws; and (3) ion exchange in which the phosphate anion replaces OH groups attached to aluminum at the crystal edges of the clay. It has been shown that extracting soils with fluoride ions or with arsenates increases the amount of phosphate ion in the soil extract. That phosphates are rarely found in ground water shows that phosphate is not appreciably leached from the soil; this is indeed very fortunate, since the level of phosphorus fertility in most of the U. S. is generally low.

The part of the soil profile known as the upper B horizon (that just under the surface soil or A horizon) makes an excellent sample in which to study the soil's mineral reserves. On a poor, highly leached, well-weathered profile, this subsoil sample will reveal only a trace of phosphorus. On the other hand, recent water-laid or bottom soils reveal high concentrations of phosphorus held as apatite or as apatite-like alluvial material.

It is good soil management to add phosphate to upland soils so that at least the plow layer will test as high as that of the recent alluvial or bottom lands. This can be accomplished either by occasional heavy single applications or by repeated small applications. Phosphates are fertilizers for the soil rather than for the crop since the soil will hold them firmly. Nitrogen, in contrast, is more nearly a fertilizer for the crop, since it may be lost from the soil in percolating water. Phosphates are applied in amounts that build the soil supply beyond the amount removed annually by crops.

Estimating Phosphorus Needs

The addition of phosphorus to the soil may have a twofold purpose:

1. *To insure a good reserve supply of phosphorus in the inorganic or mineral, the organic, and the absorbed forms. Storage in all these forms is possible and desirable ("corrective" treatment).*

2. *To furnish an active form of phosphorus as a starter fertilizer for immediate stimulation of the crop.*

The first objective is reached by using the pulverized natural mineral forms like rock phosphate. The second objective is best insured by applying highly soluble forms of phosphate at the time of seeding.

Corrective Phosphorus Treatments

Table 4 lists the amounts of phosphorus that should be added to soils of various tests. Both the P_2O_5 and the soluble test values are given for reference. These values were obtained by using the strong acid-fluorine extracting agent.

The second column gives the suggested amount of P_2O_5 to furnish in the active form for current needs. This would be supplied with the processed phosphates such as superphosphate, triple superphosphate and mixed fertilizers as a starter fertilizer.

The third column gives the amount of P_2O_5 needed in the longer-lasting, rock phosphate form to rebuild the soil reserve. Once this full correction has been made, the phosphorus level may be maintained by using annual starter treatments. Under these conditions, the natural mineral phosphates can be used for the maintenance. Amounts should be equal to or slightly above those removed by cropping.

Active Phosphorus

Two things must be considered when using the soil test to find the amount of highly soluble phosphorus to use as a placement within or along-side the row with the seeding: (1) the particular crop and (2) the test figure for the amount of soil phosphorus taken out by the weak acid-fluoride extracting reagent used for that test.

Table 5 gives some suggested amounts of soluble or processed phosphatic fertilizers to apply for various kinds of crops, in relation to test results found by this weak extracting reagent.

These data may be considered as a refined test of the more active portions of phosphorus in the soil, since the weak reagent brings only the more active fraction into solution for test. A test showing a high amount of this active fraction indicates the presence of a large amount of reserve phosphorus to provide the active forms. Forms of phosphorus are shown in Figure 2.

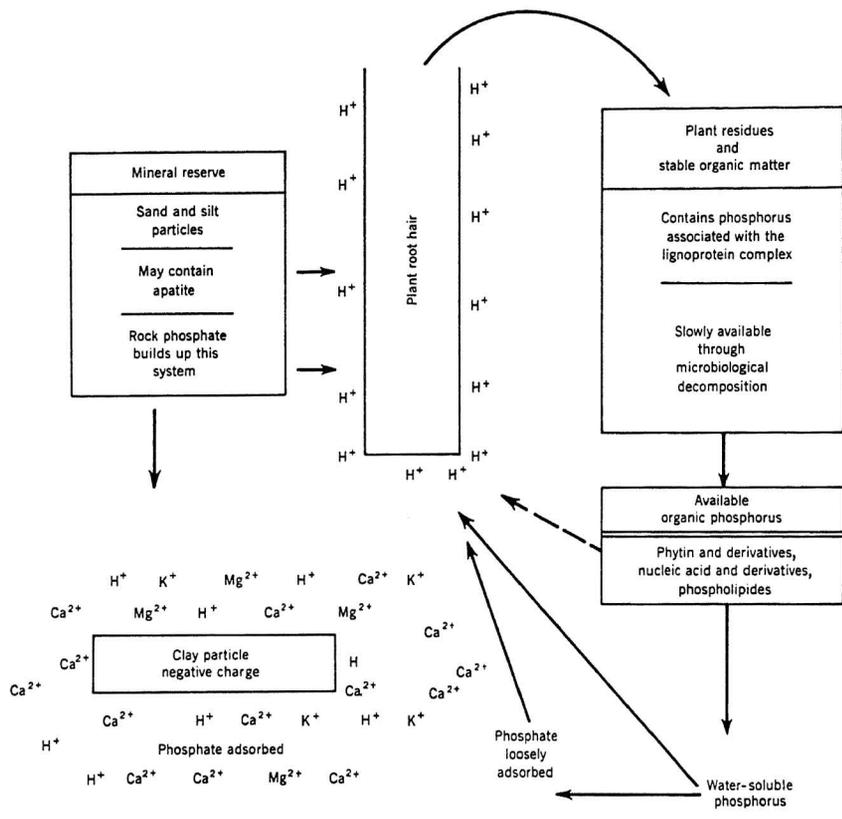


Fig. 2—Diagrams of some of the important forms of phosphorus in the soil.

TABLE 4
CORRECTIVE PHOSPHORUS APPLICATIONS IN POUNDS PER ACRE SUGGESTED BY THE VALUES OF SOIL TESTS USING STRONG REAGENT

Test Values	P P ₂ O ₅	9 20	13 30	17 40	21 50	26 60	28 70	34 80	39 90	43 100	47 110	52 120	56 130	60 140	64 150	69 160	73 170	77 180	82 190	86 200
Applications (Processed Phosphates)	P	232	219	206	193	176	168	155	142	130	116	103	90	77	64	52	39	26	13	
	P ₂ O ₅	540	510	480	450	410	390	360	330	300	270	240	210	180	150	120	90	60	30	
Rock Phosphate	P	258	210	193	172	172	172	165	155	130										
	P ₂ O ₅	600	500	450	400	400	400	380	360	300										

TABLE 5
SOME SUGGESTED AMOUNTS OF SOLUBLE PHOSPHORUS TO APPLY PER ACRE FOR CERTAIN CROPS ACCORDING TO SOIL TESTS USING WEAK EXTRACTING REAGENT

Test Values by* Weak Reagent	0-6.5	0-15	6.5-13	16-30	Above 13	Above 30
	Lbs. P	Lbs. P ₂ O ₅	Lbs. P	Lbs. P ₂ O ₅	Lbs. P	Lbs. P ₂ O ₅
(Crop desired)						
Soybeans	8.6	20	0	0	0	0
Alfalfa	8.6	20	4.7	11	4.7	11
Sweet Clover	8.6	20	4.7	11	4.7	11
Corn	25.8	60	14	30	4.7	11
Fescue	25.8	60	14	30	4.7	11
Orchard Grass	25.8	60	14	30	4.3	10
Oats, Wheat Barley	25.8	60	14	30	4.3	10
Cotton	34.4	80	17	40	14	30
Tobacco	34.4	80	17	40	14	30
Potatoes	34.4	80	17	40	14	30

* Reagent values and application values are given in terms of both P and P₂O₅.

CALCIUM

MAGNESIUM

POTASSIUM

Two considerations are involved in determining soil needs for these three elements.

1. *The Total Exchange Capacity.*

Different soils hold different total amounts of calcium, magnesium, potassium, and a fourth element, hydrogen. This amount, called *total exchange capacity*, depends on the kinds and amounts of clay, silt and sand in the soil.

2. *The Ratio of These Elements.*

The total exchange capacity is, for practical purposes, a fixed amount. But we can change the ratios among the four elements within this total.

Ions of Ca, Mg, K and H are held on the tiny particles of the soil colloid. Plant root hairs exchange ions of hydrogen for the ions of calcium, magnesium and potassium the plant needs. Thus, as a soil becomes depleted through cropping, the quantity of hydrogen ions in the colloid goes up and the quantity of the other three goes down. Treatment becomes a problem of replacing the hydrogen again with the proper amounts and balance of the other three.

The negatively charged soil colloids, which are responsible for the soil's cation exchange capacity, may be divided into three main exchanger units.

The first is the humus, which is thought to furnish carboxyl or acidic groups, which enter into exchange.

The second is the clay minerals; some of these, such as montmorillonite, reveal high exchange capacities; others show low capacity like that of kaolin.

The third unit includes such materials as ferric hydroxide, which can assume colloidal character and can function as an exchange material.

Cation exchange capacity, caused by ferric hydroxides, is not always a fixed quantity, but can vary with such factors as the pH and the nature of the ion used to determine exchange capacity.

Soil Test Method

Tests are made for each of the four elements, Ca, Mg, K and H. The unit of chemical measurement used is milliequivalents (or M.E.) per 100 grams of soil. The *total exchange capacity* is the sum of these four measurements.

Hydrogen ions are measured by the buffer method; calcium is measured in a one-tenth normal

hydrochloric acid extract; magnesium and potassium are measured in an extracting solution of 25 percent sodium nitrate in water.

Total exchange capacity values generally range from 4 to 10 M.E. for sandy soils; from 12 to 20 M.E. for silt loams; and above 20 M.E. for heavy clay and highly organic soils. However, texture is only indicative of the capacity while the total exchange capacity is nearly a fixed value, changing only with time intervals of, say, 20 to 50 years.

To be useful in determining the pounds of a nutrient needed per acre, the M.E. measurement needs to be converted into pounds per acre. M.E. is a volume measurement and M.E.s of calcium, magnesium, potassium, and hydrogen differ in weight, similar to bushels of corn, wheat and oats. Here are the weight figures used for the conversion:

400 lb. of Ca per acre = 1 M.E. of Ca per 100 grams of soil.

240 lb. of Mg per acre = 1 M.E. of Mg per 100 grams of soil.

780 lb. of K per acre = 1 M.E. of K per 100 grams of soil.

1000 lb. of H per acre = 1 M.E. of H per 100 grams of soil.

To convert the M.E. test reading for an element to pounds per acre, multiply the number of M.E.'s times the number of pounds of this element per 1 M.E.

Example: A soil sample tests 5 M.E. for calcium.

5 M.E. x 400 lb. Ca = 2000 lb. Ca per acre.

In the laboratory these calculations are usually made with the aid of a conversion table (Table 6). The laboratory technician records these conversions on the report form as pounds of exchangeable K, Mg, Ca, and H per acre. The total exchange capacity (sum of the M.E. measurements for each of the four elements) is recorded in terms of M.E.

Determining the Soil Needs

The balance soil scientists recommend for the soil colloid is 75 percent calcium, 10 percent magnesium and from 2.5 to 5 percent potassium. Table 7 gives the pounds of each required per acre to give this balance in soils of different exchange capacities. These values permit fluctuation without serious damage to production. The range can be from 65 to

TABLE 6
CONVENTIONAL VALUES IN POUNDS PER ACRE
AND CORRESPONDING MILLIGRAM
EQUIVALENTS (ME) PER 100
GRAMS OF SOIL

Calcium		Magnesium	
Pounds/Acre	ME/100 gms.	Pounds/Acre	ME/100 gms.
400	1	120	.5
800	2	240	1.0
1200	3	360	1.5
1600	4	480	2.0
2000	5	600	2.5
2400	6	720	3.0
2800	7	840	3.5
3200	8	960	4.0
3600	9		
4000	10		
4400	11		
4800	12		
5200	13		
5600	14		
6000	15		
6400	16		
6800	17		
7200	18		
7600	19		
8000	20		

Potassium	
Pounds/Acre	ME/100 gms.
78	0.10
156	0.20
234	0.30
312	0.40
390	0.50

85 percent for calcium, 6 to 12 for magnesium and 2 to 5 for potassium.

The needs of a particular field are determined by subtracting the amount of the element per acre as shown by the soil test from the amount recommended in Table 7 for a soil of the same total exchange capacity (total M. E.).

Expect Improved Methods

The Table 7 guide is the best we have at present for calcium, magnesium and potassium treatments.

This table considers soils which have a medium content of organic matter (1.5 to 5 percent) and contain a clay such as montmorillonite or beidellite, naturally, or have a high exchange capacity per unit

TABLE 7
BALANCED SOIL SATURATION OF CALCIUM, MAGNESIUM AND POTASSIUM

The values below indicate the pounds per acre necessary to balance the exchange complex of the soil to the final values of 75% saturation for calcium, 10% for magnesium, and from 5% to 2.5% for potassium. These values are subject to fluctuation without seriously affecting the soil's capacity to produce. The fluctuation range is between 65% and 85% for calcium, 6% and 12% for magnesium, and 2% and 5% for potassium.

Total Calculated Exchange Capacity#	6	8	10	12	14	16	18	20	22	24	26	28	30	32
Calcium														
Lbs./Acre	1800	2400	3000	3600	4200	4800	5400	6000	6600	7200	7800	8400	9000	9600
Magnesium														
Lbs./Acre	144	192	240	288	336	384	432	480	526	576	624	672	720	768
Potassium														
Lbs./Acre	234	250	266	280	296	312	351	390	429	468	507	546	585	624

#The total calculated exchange capacity is equal to the sum of exchangeable M.E. of hydrogen, of calcium, of magnesium, and of potassium.

Whenever the hydrogen is given as "Lime Requirement," this value divided (the L.R.) by 1000 gives the M.E. of Hydrogen per 100 grams.

400 lbs. of Ca per acre are equal to 1 M.E. of Ca/100 grams of soil.
 240 lbs. of Mg per acre are equal to 1 M.E. of Mg/100 grams of soil.
 780 lbs. of K per acre are equal to 1 M.E. of K/100 grams of soil.

weight. The values also serve reasonably well for clays of the illite type and for kaolin-sesquioxide mixtures. They serve rather poorly in the case of soils of high organic matter and of low clay content.

When soil and plant research has progressed further we will likely be able to develop specific tables of amounts of fertility treatments for given crops and for special soil conditions. The amounts set up in the tables of the future will probably be different for soils of different organic matter contents, different clay contents, different kinds of clay, and for widely different cropping systems.

RECOMMENDING APPLICATIONS

Potassium

Potassium can be applied at approximately 2 pounds of muriate of potassium for each pound of potassium deficiency. Where the potassium is reported in terms of potash (K₂O), add another one-fifth pound of potash for each pound of potassium required.

Some difficulties have been experienced with single heavy applications of muriate of potassium. To avoid zones of extreme salt concentration, not more than 200 pounds of this highly soluble salt should be added at one time. Should heavy applications be desirable, such as for alfalfa, it is well to plow down approximately two-thirds of the requirement and use about one-third as a surface application. It might prove uneconomic to maintain some soils at the ideal levels of potassium saturation. This is especially true where small grains are to be grown. For crops under irrigation—hay crops and situations where heavy applications of nitrogen are used—it is advisable to keep the potassium level near ideal.

Calcium

Calcium is recorded on the soil test form as pounds of the pure element available per acre. This is subtracted from the recommended amount in Table 7 to get the deficiency in terms of elemental calcium. Formerly, this figure was converted to a tons-of-lime recommendation for the farmer. This wasn't too satisfactory unless the purity and fineness of grind were known ahead of time.

TABLE 8
POUNDS OF EFFECTIVE CALCIUM PER TON
OF LIMESTONE

Percent Calcium Carbonate (Ca CO ₃) In Lime	Percent of Lime Passing 40 Mesh Screen (with proportionate amounts through 8 and 100 Mesh)						
	50% +	45% to 49%	40% to 44%	35% to 39%	30% to 34%	25% to 29%	20% to 24%
100	400	355	320	291	267	246	229
95 - 99	388	345	310	282	259	239	222
90 - 94	368	327	294	268	245	226	210
85 - 89	348	309	278	253	232	214	199
80 - 84	328	291	262	238	219	202	187
75 - 79	308	274	246	224	205	189	176
70 - 74	288	256	230	209	192	177	165
65 - 69	268	238	214	195	179	165	153
60 - 64	248	220	198	180	165	156	142
55 - 59	228	203	182	166	152	140	130
50 - 54	208	185	166	151	139	128	119
45 - 49	188	167	150	137	125	116	107
40 - 44	168	149	134	122	112	103	96

TABLE 9
POUNDS OF EFFECTIVE MAGNESIUM PER TON
OF LIMESTONE

Percent Magnesium Carbonate (Mg CO ₃) In Lime	Percent of Lime Passing 40 Mesh Screen (with proportionate amounts through 8 and 100 mesh)						
	50% +	45% to 49%	40% to 44%	35% to 39%	30% to 34%	25% to 29%	20% to 24%
40 +	120	107	96	87	80	74	69
35 - 39	105	93	84	76	70	65	60
30 - 34	91	81	73	66	61	56	52
25 - 29	77	68	62	56	51	47	44
20 - 24	63	56	50	46	42	39	36
15 - 19	48	43	38	35	32	29	27
10 - 14	34	30	27	25	23	21	19
5 - 9	20	18	16	14	13	12	11
1 - 4	7	6	6	5	5	4	4

To use Tables 8 and 9 find out the percent of calcium carbonate, magnesium carbonate and calcium carbonate equivalent in the limestone you are considering and also what percent of the crushed stone will go through a 40-mesh screen. The man you buy from can tell you this. Look on this table for the percent of calcium carbonate or magnesium carbonate, then read across to the column that shows the percent of fineness. The number where these lines cross is the number of pounds of effective calcium or magnesium in each ton of limestone. In the example marked on table I there is 262 pounds of calcium—66 pounds of magnesium in table II. Table I can also be used in connection with correcting acidity by substituting percent calcium carbonate equivalent for calcium carbonate.

The present method is to record the deficiency in terms of calcium. A table (see Table 8) is provided on the back of the test form that gives adjustments for fineness of grind and purity. The farmer takes this to the dealer, gets the purity and fineness figures from the dealer and checks the table to see how many tons will be required to furnish the actual Calcium (Ca) his field needs.

One other factor must be considered. Limestone applied recently and not well mixed with the soil will not likely be revealed by the soil test. Such known recent additions, if well mixed in the soil, should be credited as part of the necessary treatment already applied. Limestone applied on the surface many years previous to the soil test will not likely be recorded either but it deserves but little credit when interpreting the test report.

Stones ground finely enough to pass a 100-mesh sieve (10,000 openings per square inch) react rapidly enough to furnish a considerable amount as a "starter fertilizer," which will be available to plant roots in a few months or less. The less finely pulverized material may be viewed as "reserve or sustaining fertility" which will react slowly. It is believed that 40-mesh calcium stone will react completely in most calcium-deficient soils within 12 months. Coarser particles give focal points throughout the soil around which a thin soil layer is saturated with calcium.

The adjustments for fineness in Table 8 take into consideration both present needs for the finely ground stone and reserve needs for coarser material.

Limestone needs of less than 2 tons per acre are not usually reported but, if reported, they might be helpful to the farmer in determining the order of priority of liming various fields. Normal crop response can be expected from the application of fertilizers if the calcium saturation of the soil is near 70 percent and if the pH is near 6.0 or above. About 250 pounds of limestone are removed or lost per acre per year.

The importance of highly reactive limestone is more evident whenever full or heavy nitrogen treatments are used. When heavy nitrogen applications are in the soil management plan, the farm operator should consider making up his calcium shortage, even if it requires less than 2 tons of limestone.

Magnesium

Most Missouri soils have adequate magnesium. A deficiency can be corrected by using either dolomitic agricultural limestone or the more soluble magnesium sulfate salt.

Dolomite limestone is a combination of calcium and magnesium carbonates. This combination may appear in almost any ratio. All but a few highly calcium limestones carry some magnesium carbonate. If these two components are equal as carbonates in the pure dolomite stone, 45.72 percent by weight is magnesium carbonate and 54.27 percent is calcium carbonate. This would give about 13.17 percent magnesium and 24.1 percent calcium, or about 263 pounds of the element magnesium and 482 pounds of calcium per ton of pure dolomite.

Most of the dolomitic limestones in Missouri south of the river approach a high degree of purity. The Valley dolomite at Bonne Terre analyzes 228 pounds of magnesium and 489 pounds of calcium per ton of dried stone.

The effects of fineness of grind and purity apply to magnesium as well as calcium. Table 9, which also appears on the back of the Missouri Soil Test Report form, shows the pounds of effective magnesium available in dolomitic limestones of various degrees of purity and fineness of grind.

The Soil Test Report form suggests that the farmer figure the amount of limestone needed for calcium, magnesium, and pH correction; then use whichever figure is highest. Blanks are provided for this figuring on the back of the form. However, in cases where the tonnage required to meet magnesium deficiency is much greater than that required to correct calcium deficiency and pH, the farmer is advised to consult the county agent.

In these cases the agent can recommend meeting the calcium requirement with dolomitic limestone and making up the magnesium deficit with annual applications of magnesium salt. Sulfate of potash magnesium is recommended for this annual treatment at a rate of 18 to 21 pounds magnesium per acre on soils with a magnesium saturation of 5 percent or below (see Table 7; recommended level 10 percent).

HYDROGEN

and

Other Ionic Saturation

The measurements of exchangeable calcium, magnesium, potassium, and hydrogen are capacity measurements. They measure the soil's exchange capacity. Capacity measurements are of most value

whenever calculations for the amount of soil treatment in pounds per acre are to be made.

Measurements of the intensity of an ion also can be made in some instances; that is, the intensity of the ionization and activity of elements as electrically charged ions, rather than as compounds. The measurement of the activity of the hydrogen ion, reported as pH* of the soil, is useful in interpreting the soil conditions that help or hinder plant growth. It would be of greater importance to know the pCa, pMg, and the pK (activities of calcium, magnesium, and potassium) since these measurements are related to the ionic nutrient activity in the plant root's environment rather than to the ionic activity of the non-nutrient hydrogen. But the measurement of the activity of these other ions is extremely difficult. At present, pH is the only practical activity measurement available.

The pH of the soil-water system is related to the ionic saturation of the colloidal complex, especially to the ratios of the hydrogen-calcium saturations. The type of colloid present in the soil controls the activity of an ion, such as hydrogen. The differences between clay groups, humus, and sesquioxide colloids can be shown by comparing the percentage saturation of *ions other than* hydrogen with that of hydrogen, or the pH of the entire system.

A normal Missouri soil containing beidellite clay as the mineral colloid and about 2.5 percent organic matter will show a pH of 5.0. Such soil is about 55 percent saturated by cations other than hydrogen. At the same (55%) saturation of those cations, humus mixtures under test will show a pH of 6.0; soils dominated by high amounts of clay, such as subsoils and gumbo, will show a pH of 4.6.

This information, along with cation exchange capacity, helps reveal the nature of the colloid.

It might be concluded that colloid mixtures which show a high pH for a given saturation of calcium, magnesium and potassium cations will grow plants at a lower cation saturation than soils with a low pH. Additional research will be necessary to sort out the importance of the type of soil colloid in relation to specific crop production.

Effects of Salt on pH Value

The activity of hydrogen ions as measured with the soil in distilled water is designated by the symbol pH_w in the following discussion. That measured with soil in a dilute solution of calcium is designated pH_s .

The pH_w of soils, determined in a mixture of

*pH may be defined as the logarithm of the reciprocal of the active hydrogen ions in grams per liter.

equal amounts of soil and water, is influenced by the amount of soluble salts present, as well as the degree of cation saturation and the kind of clay in the soil. The exchangeable hydrogen in a soil relatively free of salts dissociates to only small degree as active hydrogen in the water surrounding the soil particles. When salts are present in the water, the hydrogen from the soil may enter into the solution by exchanging with the cations of the salt solution. Hence, soils containing soluble salts will release larger amounts of active hydrogen into solution, giving lower pH_w values than soils which are free of salts.

The salt content of a soil tends to vary widely. It decreases as rain water washes the salts deeper into the soil profile. It increases as capillary rise brings the salts back to the surface of the soil as it dries. Fertilization adds soluble salts to a soil; plants remove salts. Infertile, sandy, highly-leached soils usually contain very little soluble salts. Fertile, productive soils contain moderate amounts of salts. Some heavily fertilized garden soils and soils in field spots where water seeps to the surface may contain exceedingly high salt content.

Reduction in pH by Additions of Salt

The pH_w of a soil has been used extensively as a simple, rapid means of diagnosing the degree of a soil's saturation by cations other than hydrogen. The pH_w values obtained are reliable guides when soils contain average amounts of salts.

To stabilize pH values with respect to salt content of the soil, amounts of salt sufficient to overcome effects of those naturally present may be added to the soil before determining the pH. This practice has been followed for many years by the German investigators.

More recently Taylor and Schofield of England, have shown that a reliable measure of the lime potential of a soil in terms of pH can be obtained with the soil in 0.01 molar calcium chloride. Using this technique, we have found that the pH_s of highly leached soils from the Ozark uplands and from the sandy alluvial soils of southeastern Missouri may be as much as one whole unit lower than the pH_w . The value of the pH_w of soils of average salt content was lowered from 0.4 to 0.6 units by using the calcium chloride. Depressions of the pH_w amounting to 0.1 unit and less upon the addition of calcium chloride occurred when soils were exceedingly high in their content of salts.

Interpreting the pH_s of Soils

The pH_s values of soils, measured in 0.01 molar calcium, may be interpreted in terms of degree of soil saturation by cations other than hydrogen.

Such pH_s values also provide a reliable measure of the presence of free calcium carbonate. Choosing a pH_s value of 7.0 as representing 100 percent saturation of the soil by cations other than hydrogen, the degree of that saturation decreases by approximately 20 percent for each pH unit below 7.0. Thus a soil with a pH_s value of 6.0 would be 80 percent saturated and one with a pH_s value of 5.0 would be 60 percent saturated by cations other than hydrogen. The pH_s value of free calcium carbonate in a soil is 7.5. Values of pH_s in excess of 7.5 are indicative of the presence of excessive amounts of sodium, and such soils would be classed as alkali soils.

The following scale of values for interpreting the pH_s values of mineral soils is suggested:

pH_s	Interpretation
over 7.5	Alkali soil.
7.5	Free lime in soil.
7.0	100 percent saturation by cations other than hydrogen.
6.5-7.0	Ideal for alfalfa; satisfactory for most crops.
6.0-6.5	Ideal for most crops; satisfactory for alfalfa.
5.5-6.0	Satisfactory for grasses, small grains and corn.
5.0-5.5	Deficient in calcium; should be limed.
4.5-5.0	Very deficient in calcium; unsatisfactory for almost all crops.

In organic soils, the solubilities of iron and aluminum are not as great as in mineral soils and the high exchange capacities provide ample amounts of calcium at lower pH levels. Such soils may function satisfactorily for most crops at pH_s values in the range from 5.0 to 5.5.

In diagnosing and interpreting soil conditions for plant growth, it is a good idea to determine both pH_w and pH_s . The difference between the two values reflects the salt content of the soil. Low salt values suggest highly leached and infertile soils; high salt values reflect over-fertilization and wet soils. However, for diagnosing and interpreting the degree of cation saturation and the need for liming a soil, only the pH_s value should be considered.

Special Problems

Soil testing is now simple enough that we can test for many elements quickly and accurately. Unfortunately, there are still some elements for which tests are not effective. These include manganese, boron, chloride, iron, copper, zinc and molybdenum—which are referred to as trace elements—and sulfur which is usually considered a major one. There is hope that tests for these eventually will be worked out. Soil testing measures many, but by no means all, of the soil factors in crop production.

Chemical

Procedures

PREPARING THE SOIL SAMPLE

First step after a soil sample arrives at the laboratory is to dry it. This may be done by allowing it to dry slowly in the air on a plate or other suitable container for ten days or more. Another way is to place the sample in a cabinet which has dry warm air circulating through it. If the cabinet has a high capacity for drying, the samples may be dried sufficiently over night. The period and temperature of the drying should be such that the values for exchangeable potassium will not be altered and will be the same as those obtained by ten days, or more, of air-drying.

Samples should be reduced to a degree of fineness that will pass a ten mesh screen. Mechanical grinders may be used. However, those which reduce the mineral crystals to a fine powder should be avoided; such grinding releases nutrients held in the minerals which were, most likely, unavailable to plants.

SOIL ORGANIC MATTER

Procedure

Weigh or measure one gm. of ten mesh air-dry soil into a 250 ml. Erlenmeyer flask.

Add 10 ml. of normal potassium dichromate (49.03 gm. $K_2Cr_2O_7$ C.P. made up to a liter with distilled water).

By means of a 250 ml. burette with a glass stopcock, add rapidly down the side of the flask 20 ml. of concentrated sulfuric acid. Quickly swirl the mixture for ten seconds and allow it to stand for ten minutes. Add 100 ml. of water.

This mixture should stand until it has cooled to near room temperature when it may be filtered into colorimetric adsorption tubes and read on the photoelectric colorimeter. Use a red filter (610 $m\mu$ wave length), set the instrument at 100 T†, and use distilled water for this reading.

Standard

A set of standard soils of predetermined organic

matter contents should be carried through the digestion procedure so that the proper curve can be determined. Then, by comparing the transmittancy of the unknown soil with the percentage of organic matter established for that value on the curve, the percentage of organic matter in the unknown can be determined.

SOIL PHOSPHORUS (RESERVE)

Procedure

Measure 7 ml. of Bray's strong phosphorus-extracting solution (0.1 N HCl containing 0.03 N NH_4F) into phosphorus extracting tubes.

Add 1 gram of air-dry soil (use 1-gram calibrated spoon), shake for one minute and filter.

Remove 0.25 ml. of the clear filtrate and place it in the colorimetric adsorption tubes for the calcium test.

To the remainder of the filtrate add six drops of standard ammonium molybdate solution (made by pouring, with stirring, a solution of 100 gm. of ammonium molybdate in 850 ml. H_2O into 1700 ml. of concentrated HCl).

Add five drops of organic reducing solution (1 gm. of p-methylaminophenol sulfate and 3 gm. $NaHSO_3$ in 100 ml. of distilled water).

Allow this mixture to stand for one hour and read on the photoelectric colorimeter, using a red filter (650 $m\mu$ wave length) and with the instrument originally set at 100 T with distilled water.

Convert the colorimeter readings into pounds of phosphate per acre, by means of the standard curve.

Standard

The standard curve for determination of the reserve phosphorus may be constructed as follows: Prepare separate phosphorus solutions containing 1, 2, 3, 4, and 5 mgm. per liter, respectively, of phosphorus made up in distilled water. (C.P. KH_2PO_4 is a suitable salt for preparation of the standard solutions). Measure 7 ml. of each of the above solutions into separate colorimetric adsorption tubes, add six drops of the molybdate solution and five

†The abbreviation T is used for *transmittance*.

drops of the organic reducing solution to each in the series.

Read on the colorimeter after one hour, using a red filter (650 m wave length), after adjusting the colorimeter to 100 T by using distilled water. Plot the transmittancy readings against the concentrations of the series of standard solutions. One milligram of phosphorus per liter is equivalent to 13.75 pounds of phosphorus or 32 pounds of phosphate (P_2O_5) per acre of 2,000,000 pounds of soil.

SOIL PHOSPHORUS (ACTIVE)

Procedure

Measure 7 ml. of Bray's weak phosphorus-extracting solution (0.025 N HCl containing 0.03 N. $NH_4 F$) into phosphorus extracting tubes.

Add 1 gram of air-dry soil, shake for one minute and filter.

To the filtrate add six drops of standard ammonium molybdate solution and follow through as in the previous procedure up to the standard to be used.

Standard

The standard curve for determination of the active phosphorus may be constructed as follows: Prepare separate phosphorus solutions containing 0.5, 1.0, 1.5, and 2.0 mg. per liter, respectively, made up in distilled water. Measure 7 ml. of each of the above solutions into separate colorimetric absorption tubes, add six drops of the molybdate solution and five drops of the organic reducing solution to each. After one hour read on the colorimeter, using a red filter (650 $m\mu$ wave length), after adjusting the colorimeter to 100 T by using distilled water.

Plot transmittancy readings against the concentration of phosphorus of the series of standard solutions. The 0.5 mg. of phosphorus per liter is equivalent to 6.88 pounds of phosphorus and 16 pounds of P_2O_5 per acre. The solutions in this range develop small amounts of color. An adsorption tube of larger diameter may be used to obtain a more sensitive test.

DEGREE OF SOIL ACIDITY AS SOIL PLUS WATER pH_w

Procedure:

Calibrate the glass electrode by using buffer solution of pH 4.0 and pH 7.0. Be sure to allow the electrodes to soak in distilled water for 15 minutes and also allow time for the instrument to become warm. For the calibration procedure, follow the outline furnished by the manufacturer of the instrument.

Measure 5 gm. of soil into a waxed paper cup, add 5 ml. of distilled water and shake gently until the soil is well mixed with water.

Insert the glass electrodes, shake the cup of soil gently, depress the switch button and read the soil pH.

Between readings of either buffers or soils be sure to rub the glass electrode with filter paper, or with fingers, and wash well with distilled water. This procedure must be followed to remove any film from the glass electrode, which will interfere with subsequent readings.

DEGREE OF SOIL ACIDITY AS SOIL PLUS SALT pH_s

Add one drop of a 1-molar calcium chloride solution to a 5 gm. sample of soil to which 5 ml. of water have been added. Take a reading in same manner as for pH_w . Following the determination of pH_s , 10 ml. of the buffer used for measuring the exchangeable hydrogen may be added. The quantity of salt added for determining pH_s is not great enough to disturb the determination of the exchangeable hydrogen.

EXCHANGEABLE HYDROGEN

The same samples of soil used for the determinations of the pH_w and pH_s are suitable for the determinations of total hydrogen.

Calibrate the glass electrode of the pH meter carefully with a nitrophenol buffer 8 gm. paranitrophenol, 40 gm. $Ca(CH_3 COO)_2 \cdot H_2O$ and 0.625 gm. MgO made up to 1000 ml. with distilled water and the solution adjusted to pH 7.0 by adding either HCl or MgO as required to a pH of 7.0.

Add to the soil samples used in the pH determinations, 10 ml. of the nitrophenol mixture; stir thoroughly for 30 seconds and allow to stand for 30 minutes.

Stir again; insert the electrodes; shake the soil cup gently to insure contact; depress the switch and read the meter. Each change of 0.1 in pH on going from 7.0 to 6.0 is equivalent to 1 M.E. of hydrogen per 100 gm. soil.

Should the sample show more than 10 M.E. hydrogen per 100 gm. soil, use 2.5 gm. of the soil sample and repeat the entire procedure. In this case a change of 0.1 pH on going from 7.0 to 6.0 is equivalent to 2.0 M.E. of hydrogen per 100 gm. soil.

EXCHANGEABLE POTASSIUM

(*Tetraphenyl Boron Method*)

Procedure

Measure 10 ml. of the sodium nitrate extraction solution (250 gm. $NaNO_3$ per liter) into a vial; add five grams of air-dry soil (use a calibrated five-gram spoon).

Allow the soil to stand in the extracting solution for five minutes, then shake vigorously for 15 minutes and filter.

Transfer 0.5 ml. of the soil extract to a colorimetric adsorption tube.

Add three drops of K-B reagent. (Made up of 3 gm. of $Na_2 HPO_4 \cdot 7 H_2O$, 0.105 gm. of citric acid and 30

gm. of sodium tetraphenylboron dissolved in one liter of distilled water; these reagents must be mixed in a polyethylene beaker and stored in polyethylene bottles for best keeping quality.)

Add 1.0 ml. of K-C reagent. (Made up of 1.85 gm. of citric acid, 7.15 gm. of sodium citrate and 30 gm. of sodium lauryl sulfate dissolved in distilled water, with 7.1 ml. of concentrated HCl added and the whole solution made up to one liter final volume. The final pH should be near 2.0). After addition of the K-C reagent swirl the tubes to insure mixing, then add 4.5 ml. of distilled water.

Shake tubes vigorously or stir to insure a dispersion of the potassium precipitate.

Determine transmittance of the light by adjusting the electric colorimeter to 100 T with distilled water. Use wave length of 540 μ . or a green filter. Convert the reading to M.E./100 gm. soil or to pounds per acre with a standard curve.

Standard Curve

Transfer 0.5 ml. of each of the following solutions to separate colorimetric adsorption tubes: 20 mg. of potassium per liter, 50 mg. of potassium per liter, and 80 mg. of potassium per liter. Prepare them in triplicate.

Add three drops K-B reagent, 1.0 ml. of the K-C reagent and 4.5 ml. of distilled water and proceed as outlined above for the soil sample.

Plot the average of each set of three transmittancy readings against the corresponding concentrations of the solution.

The point on the curve for the concentration of 20 mg. per liter is equivalent to 0.102 M.E. potassium per 100 gm. of soil, or to 80 pounds per acre; the point for 50 mg. is equivalent to 0.256 M.E. or to 200 pounds; and the point for 80 mg. is equivalent to 0.410 M.E. or to 320 pounds per acre.

EXCHANGEABLE POTASSIUM

(Cobalti-Nitrite Method)

Procedure

Measure 10 ml. of the sodium nitrate extraction solution (250 gm. of NaNO_3 per liter) into a vial; add 5 gm. of air-dry soil (use a calibrated five-gram spoon).

Allow the soil to stand in the extracting solution for 5 minutes; then shake vigorously for 15 minutes and filter.

Place the filtrate in the water bath to cool. The temperature range of the water bath should be between 15° and 25° C. Tap water usually falls in this range.

Measure 2 ml. of alcohol (95 percent ethyl or 1:1 isopropyl and amyl alcohols) into a colorimetric adsorption tube. The alcohol must be of the same temperature

as the water in the water bath. This can be accomplished by placing a burette inside of a condenser and connecting the condenser with the water tap or by using a Smith automatic pipette which is placed in the water bath.

Add six drops of a sodium cobalti-nitrite solution [50 gm. of $\text{Co}(\text{NO}_3)_2$ plus 300 gm. of NaNO_2 and 25 ml. of glacial acetic acid made up to one liter]. The cobalti-nitrite solution should also be placed in the water bath and brought to the same temperature as that of the other reagents. The stock supply should be kept in a cool dark place.

Add forcibly from a medical syringe, 2 ml. of the cooled soil extract (automatic transfer pipettes may be used instead of medical syringes). The addition of the soil extract must be in such a manner that uniform mixing is accomplished. Avoid drops from the medical syringe or direction of the stream against the side of the adsorption tube.

After allowing the mixture to stand for five minutes but not over 15 minutes, read the results on the colorimeter. Use the red filter and adjust the instrument at zero using distilled water.

Convert the reading to M.E. per 100 gm. or to pounds per acre with the use of the standard curve.

Standard

The standard curve for potassium may be prepared as follows. Place approximately 15 ml. each of the following in separate vials and cool in the water bath: (a) potash extracting solution, (b) standard with 20 mgm. of potassium per liter of solution, and (c) standard with 5 mgm. of potassium per liter of solution. (The standard potassium solutions should contain sodium nitrate in the same concentration as the extracting solution).

To each of twelve clean colorimetric absorption tubes add 2 ml. of alcohol, and six drops of cobalti-nitrite solution.

Add forcibly with a medical syringe 2 ml. of the potash extracting solution to four of the adsorption tubes. Add forcibly 2 ml. of the solution of 20 mg./D of potassium per liter to four of the adsorption tubes. Add 2 ml. of the solution of 50 mg. of potassium per liter to four of the adsorption tubes.

After five but not over 15 minutes, read on the colorimeter using the red filter and after adjusting the instrument at zero with distilled water.

Plot the average of each set of the four transmittancy readings against the corresponding concentrations of the solutions. The point on the curve for a concentration of 20 mg. per liter is equivalent to 0.102 M.E. potassium per 100 gm. of soil, or to 80 pounds potassium per acre. The point on the curve for 50 mg. per liter is equivalent to 0.256 M.E. of potassium per 100 gm. of soil or to 200 pound potassium per acre.

EXCHANGEABLE MAGNESIUM

Procedure

Place 0.25 ml. of the soil extract, obtained in the potassium tests, in a colorimetric adsorption tube.

Add 4.75 ml. of distilled water. Add 0.5 ml. each of the following four reagents:

Reagent A—4.4 gm. $\text{Ca}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot \text{H}_2\text{O}$, 0.37 gm. $\text{Al}_2(\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O}$, 0.278 gm. of $\text{MnSO}_4 \cdot \text{H}_2\text{O}$, and 1.1 gm. $\text{Na}_3\text{PO}_4 \cdot 12 \text{H}_2\text{O}$ are dissolved in 600 ml. of distilled water with 10 ml. of conc. HCl, then 10 gm. of hydroxylamine hydro-chloride are added and the final volume brought to one liter with water.

Reagent B—Measure one liter of distilled water, add while stirring 20 gm. of polyvinyl alcohol, dissolve completely by stirring and gradual heating. Do not allow the temperature to rise above 90°C after the polyvinyl alcohol has been dissolved. Add 0.06 gm. of $\text{CuSO}_4 \cdot \text{H}_2\text{O}$.

Reagent C—0.033% thiazol yellow solution.

Reagent D—10% NaOH.

Each reagent should be added with force to insure mixing. After the last reagent is added, shake vigorously to insure complete mixing.

Adjust the colorimeter to wave length 540 $m\mu$ (green filter).

Place water in the adsorption tube and set the transmittance at 100.

Convert the readings of transmittance with M.E. per 100 gm. of soil or to pounds per acre by using a prepared standard curve.

Standard

The standard curve may be prepared as follows. Measure 0.25 ml. of each standard solution containing 10, 50, 100 and 200 mg. of magnesium per liter, and place in colorimetric adsorption tubes; prepare in duplicate.

Add 4.75 ml. of distilled water and 0.5 ml. of each of the magnesium reagents, A, B, C, and D. Shake well to insure mixing.

With the colorimeter set at 540 $m\mu$ wave length or with the green filter in place, adjust the colorimeter to 100 transmittance with distilled water in the adsorption tube. Read the standards and plot transmittance readings against the concentrations of magnesium. Do not prepare a K-A magnesium blank since this blank gives rise to erratic transmittancy readings.

To plot the curve, connect the points representing 10, 50, 100, and 200 mg. per liter. The magnesium standard containing 5 mg. per liter is equivalent to 0.83 M.E. per 100 gm. of soil or to 200 pounds magnesium per acre.

EXCHANGEABLE CALCIUM

Procedure

Add 1.75 ml. of ammonium hydroxide (0.5 percent solution) to the 0.25 of soil extract obtained in the procedure for phosphorus.

Add forcibly from an automatic pipette 2 ml. of soap solution. (Shake 7.05 gm. of oleic acid in a nearly saturated solution into 1.6 gm. of KOH in 5 ml. of distilled water, transfer this mixture to a flask. Use 50 ml. of 70 percent ethyl alcohol to make the transfer, reflux for one hour and add enough distilled water to bring the volume to 250 ml. Mix 20 ml. of the above mixture with 100 ml. of 3 percent Duponol solution; allow to stand over night; filter if necessary.

On the addition of the soap solution, a white turbidity will start to develop. Allow 20 to 30 minutes to complete the development and then read on the colorimeter. Use the blue filter (420 $m\mu$) for the reading, and adjust the colorimeter to 100 transmittance with distilled water as the test liquid.

Convert the reading into M.E. per 100 grams of soil or pounds exchangeable calcium per acre by means of the standard curve.

Standard

The standard curve for calcium may be prepared as follows. Prepare two standard solutions of calcium, one containing 160 and the other 400 mg. per liter.

Measure 0.25 ml. of each standard calcium solution, in duplicate, into colorimetric adsorption tubes and then add to each 1.75 ml. of ammonium hydroxide solution.

Add forcibly from an automatic pipette, 2 ml. of soap solution described above.

After allowing them to stand for 30 minutes read them on the colorimeter. Use the blue filter for the reading, and adjust the instrument to 100 T with distilled water as the test liquid.

Plot the transmittancy readings against the concentrations of the standard solutions. A concentration of 160 mg. per liter is equivalent to 5.6 M.E. per 100 gm. of soil, or 2240 pounds of calcium per acre; 400 mgm. per liter are equivalent to 14 M.E. per 100 gm. of soil or 5600 pounds of calcium per acre.

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