Testing Missouri Soils

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FOREWORD

Intensive cultivation of the soil for larger crop yields under 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 using up 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; nevertheless, 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.

Chemical tests of the soil are one of the first means of taking inventory of the productive assets of agriculture. They are measuring 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 tests have moved from the Experiment Station to the county agent laboratories and thence out to the farmers' own fields. Reports of such tests 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 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, 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 over much of Missouri, are bringing agricultural betterment from the ground up.

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TESTING MISSOURI SOILS

E. R. GRAHAM

Chemical tests for estimating the levels of plant nutrients in soils may well be used more extensively. Considerable progress has been made in developing methods that are rapid, analytically feasible, and accurate enough for practical purposes. However, some confusion still remains regarding the interpretations of the results from these chemical measurements of the soil and their use for recommendations for fertilizers and future soil-building programs.

It is the purpose of this publication to report the chemicals and their reactions used in making the soil tests, and to discuss briefly how the chemical measurements are converted into fertilizer recommendations. It is the hope that this discussion will contribute to a better understanding of the fertility needs of many of our soils by the farmer, the fertilizer producers and the agronomists, all of whom are interested in the problem of maintaining the fertility of our soils.

PARTICULAR FACTORS IN PRODUCTIVITY TESTED

While a great many factors of the soil enter in to determine its productivity, it is not the object of this report to consider all of the various tests for them now being used, nor to compare one test with another. Rather it is the aim to report the workable tests now used in Missouri which, according to experience to date, have given satisfactory results. In some few instances improvements are anticipated in both the chemical procedures and the field correlations which, when once available, will be worked into this system. The chemical tests now being used as helps to estimate the factors entering into the productivity of the soil are as follows:

1. Organic matter (per cent by weight)
2. Extractable phosphorus (Bray's extracting solution)
3. pH (Glass electrode)
4. Exchangeable hydrogen
5. Exchangeable potassium
6. Exchangeable magnesium
7. Exchangeable calcium

While the above seven are not all the soil factors in control of productivity, they are the major fertility items lending themselves to easy measurement. They are also sufficient, when considered in their measured amounts in relation to each other, to give a clearer picture of the part the soil and the chemical activities play in crop production.

These seven tests reveal usable information as to the nature of the soil colloid from the point of view of its per cent saturation and the ratio of the amounts of potassium, magnesium and calcium, on the surface of the colloidal particles. The tests also reveal the phosphorus fertility level as well as the amount of organic matter present.

The soil colloid, that is, both the organic matter or humus and the clay in their manifold reactions, is the major center of fertility supply and its delivery to plants. These tests of the nature of that colloid are reaching into the soil to bring out of it a better understanding of how the soil feeds the plant a well balanced ration.

THE COLLOIDAL COMPLEX OF THE SOIL

If one is to understand soil testing under mid-west conditions, the importance of the colloidal complex of the soil cannot be ignored. Soil colloids are principally inorganic, but highly decomposed organic matter has colloidal properties, as shown by many soils. The very small particles of mineral clay and humus manifest certain physicochemical phenomena which are of great importance. Such fundamental properties as plasticity, aggregation, adsorption and many exchange reactions involving elements active as ions on the surface of these colloidal particles are conditioned by the colloidal complex.

These properties are illustrated by the wet soil being readily molded, by its formation of nice granular structure, its capacity to filter out of solutions many chemical ions, and to put into that solution going through the soil many other chemical ions in exchange. It is this principle by which the colloid can be stocked through soil treatments with fertility for delivery to the plants. It has been suggested that the plants exchange hydrogen for fertility as roots make contact with colloidal surfaces.

For a given unit of mass, as an example, the humus colloids are more active then the clay colloids. But since so many of our soils have a low humus content, which is becoming ever lower through cropping and erosion, the clay fraction becomes even more important. There are many different types of clay minerals which exhibit different colloidal properties but all of them exhibit adsorption and exchange of ions, the basic chemical activities in the soil for plant feeding. Also, clays vary greatly in their hydration or water-combining properties, their total adsorptive capacities, and amounts and kinds of adsorbed ions. The possibility of different kinds of clay, different amounts of clay, and different humus contents of soils brings corresponding possibility for great variation in ion exchange capacity, the supply of plant nutrients in store, and the other physico-chemical characteristics of the soil. Soils containing much sand, or little organic matter or clay of the kaolin type have a low ion exchange capacity. They do not swell nor shrink much. They are easy to till. Soils that are low in sand content, moderate in organic matter content and containers of montmorillonitic clay have a high exchange capacity. They usually swell and shrink considerably. They are difficult to till. The particular physico-chemical properties of soils lend themselves to many modifications through cropping and treatments. Some of the modifications and characteristics will be discussed.

IONIC SATURATION OF THE COLLOIDAL COMPLEX

Merely to know that the soil colloid has ion exchange capacity is not enough. A determination of the amounts and kinds of nutrient elements in the active forms as ions adsorbed and subject to exchange from the clay surface to the root surface and vice versa is of great importance. Two soil areas may have the same total ionic exchange capacity, yet they may show extremely different soil-plant relationships, because they contain different amounts and kinds of adsorbed ions. A helpful term for charactizing the ions on the soil colloid is "ionic saturation". This refers to the concept of a collection of ions (elements and compounds) held on the surface of the clay but possibly active in exchange for, and in reaction with, other substance coming in contact. By measuring the amounts of the various ions exchangeable these can be converted into per cent of the colloid adsorption surface for any ionic saturation, by dividing the amount of the particular ion by the total ionic adsorption capacity. The per cent ionic saturation can be considered in another way by using the sum of the ions other-than-hydrogen and dividing this sum by the total ionic capacity. In this instance the term "per cent base saturation" will be used, since it excludes the hydrogen, or the ion with the "acid" characters and leaves only those with "basic" characters. The particular value in the study of per cent ionic saturation is of great importance when nutrient balance for the plants is to be considered.

INTERACTIONS BETWEEN COLLOIDAL COMPLEX AND PLANT ROOT FOR PLANT NUTRITION

It has been demonstrated that the exchangeable ions adsorbed on the surface of the colloidal particles are readily available to plants.

Several theories have been presented to explain this phenomenon, all of which reveal the exchange of ions between the surface of the soil colloid and the root hair or vice versa. It is generally assumed by some that the root hair by its respiration of carbon dioxide into the soil water furnishes H (hydrogen ions of sufficient concentration to replace calcium, magnesium and potassium and other nutrient ions from the soil colloid. Jenny and others (5)* believe that the active root hair membrane furnishes hydrogen, which by contact replaces adsorbed plant nutrients. Some have objected to this theory on the basis that the root hair is larger than a single clay particle. They forget that there is an infinite number of clay particles present which may well arrange in film presenting large areas of surface. Others have found thermodynamic irregularities occurring in the contact concept. They propose that the root hair enters only the very outer layer of the diffuse layer of the adsorbed ions. The concentration of ions in this layer may be similar in ratio to those used in nutrient solutions, while the ratio of total adsorbed ions is much different. This apparent discrepancy could be explained by considering adsorbed ion activity. Once the exchange has taken place the ions are taken in by the root, used by the plant in various physiological transformations and usually removed through cropping. In case the crop is allowed to return to the soil those chemical elements contained in the plant will return to the soil colloids again for another cycle as the plant undergoes decomposition. In the more common case of crop removal, this addition of organic matter for building up the soil supply does not take place, as was true under virgin conditions. This secondary assembly line in the virgin cycle is broken. Another cycle of great importance is associated with soil minerals, should the silt, sand or clay separates of the soil contain weatherable minerals, then the ions from these minerals are transferred through weathering process encouraged by organic matter and clay (3), to the surface of the colloidal complex. In cases where the sand, silt, and clay of the soil are composed of quartz, devoid of nutrient elements, and consist of other extremely resistant minerals, then the supply of exchangeable fertility on the surface of the colloidal complex can be rejuvenated only by additions of nutrient elements as fertilizers, manures and plant residues. One of the basic concepts of this theory holds to the belief that the roots must sample the soil colloid system, that the nutrient ions are strongly adsorbed there, and that they do not move to the plant except by exchange for some other ions. The above concept as presented diagrammatically in Fig. 1 is helpful in visualizing

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*See References on page 22.

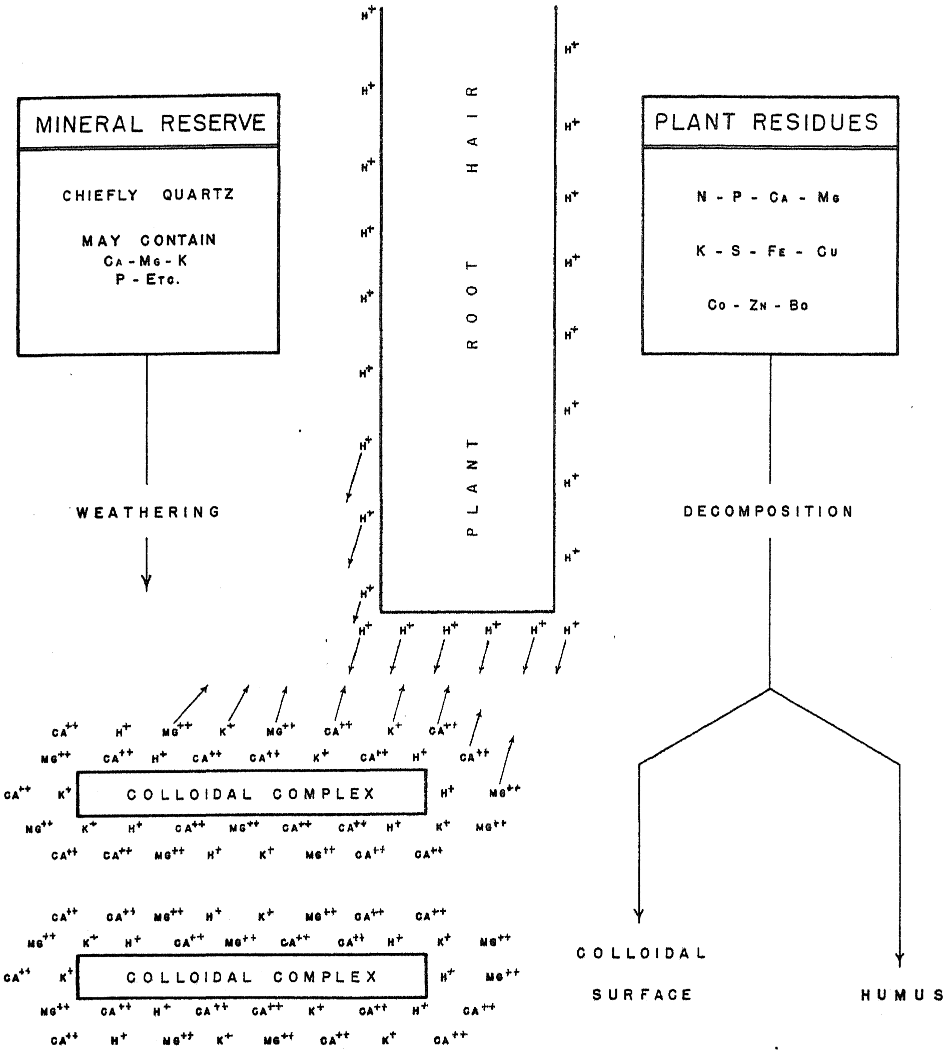

Figure 1.—Diagrammatic representation of inter-actions between root, colloid, plant residue and mineral reserves for plant nutrition.

the activities in the soil for calcium, magnesium, potassium, manganese, copper, cobalt, iron, phosphorus, and nitrogen. However, nitrogen and phosphorus, according to present concepts, must be handled as special cases to be discussed later.

MAKING THE SOIL TESTS

Using the concept that the root exchanges the hydrogen of origin around its surface for other positively charged nutrient ions on the surface of the soil colloid, the chemical tests have been designed to exchange some known ion for those unknown ones in a given amount of soil. These so removed from the colloid by a standard solution can then be taken away from the soil in that means and measured as to kinds and amounts. Details are given for the procedures needed in treating the soil sample and those in making and using a known or standard for comparison to determine the amounts of items present.

Soil Organic Matter: (4)

Procedure: Weigh or measure 1 gm. of 10 mesh air-dry soil into a 250 ml. Erlenmeyer flask. Add 10 ml. of normal potassium dichromate (49.03 gms. C. P. K_2 Cr_2 O_7 made up to a liter with distilled water).* By means of a 250 ml. glass stopcock burette, add rapidly 20 ml. of concentrated sulfuric acid. Quickly swirl the mixture for 10 seconds and allow it to stand for 10 minutes. Then add 100 ml. of water. This mixture should stand until it has cooled to near room temperature when it may be filtered into colorimeteric adsorption tubes and read on the photoelectric colorimeter. For the reading use a red filter (620 $m\mu$.) and set the instrument at zero using distilled water for this reading. Standard: A set of standard soils of predetermined organic matter content should be carried through the digestion procedure so that the proper curve can be determined, then by comparing the transmittancy against the per cent of organic matter, the percentage organic matter in the unknown can be determined.

Interpretation of Tests for Organic Matter. The importance of the amount of soil organic matter to the producer of crops cannot be over emphasized. This information is a valuable help in making plans for soil improvement, cropping systems, and for making recommendations for the use of mixed fertilizers, nitrogen and lime. It is unfortunate that some simple test to differentiate the forms of organic matter in the soil has not been devised. The organic matter test described above measures the total amount of it present. It does not measure active organic matter. For example, sweet clover can be plowed under with the result that corn yields are markedly increased, yet the per cent of total organic matter will not be changed enough by one crop of sweet clover to show a difference in the test of the soil for

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*Enclosed in parenthesis are the chemical details by which the solutions are made up for use.

it. In case, however, a farmer has been adding manure or turning under green manure regularly for 10 years or so, then the total organic matter will be modified enough to show in the soil test. Fields which have been spot-eroded, and different soil types always show differences in the organic matter test.

Many systems of soil testing include tests for the nitrate ion. This nitrogen results from the transformation of the organic matter or the addition of nitrogen materials. This particular test has been omitted here because the soil samples must be taken well in advance of the planting date, hence the nitrate shown at any one particular sampling time could very well be much different than the nitrate supply during the entire growing season. The use of the test of the total organic matter as a basis for predicting the supply of nitrogen during the season seems to be much more logical. Such information as the nitrogen requirements of the crop to be grown, the previous cropping history, and the amount of green and farm manures applied is absolutely necessary. This must be integrated with the information from the test of total organic matter in order to arrive at the nitrogen status of a given soil area. For further information on this problem see Klemme (6) and Woodruff (10).

Soluble Phosphorus (2)

Procedure: Measure 7 ml. of Bray's phosphorus extracting solution (.1N HC1 containing .03N NH_4F) into phosphorus extracting tubes. Add 1 gm. of air-dry soil (use a 1 gm. calibrated spoon), shake for one minute and filter. Remove ¼ ml. of the clear filtrate and place it in the colorimeteric adsorption tubes for the calcium test. To the remainder of the filtrate add 6 drops of standard ammonium molybdate solution (pour, with stirring, a solution of 100 grams of ammonium molybdate in 850 ml. H_2O into 1700 ml. of concentrated HC1). Then add 5 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 1 hour and read on the photoelectric colorimeter, using a red filter and with the instrument originally set at zero with distilled water. With the standard curve convert the colorimeter readings into pounds of phosphate per acre. Standard: The standard curve for the phosphorus determination may be constructed as follows: prepare separate phosphate solutions containing 1, 2, 3, 4 and 5 mgms/liter respectively of phosphorus made up in distilled water. Measure 7 ml. of each of the above solutions into separate colorimenteric adsorpton tubes, add 6 drops of the molybdate solution and 5 drops of the organic reducing solution to each in the series. Read on the colorimeter after 1 hour using

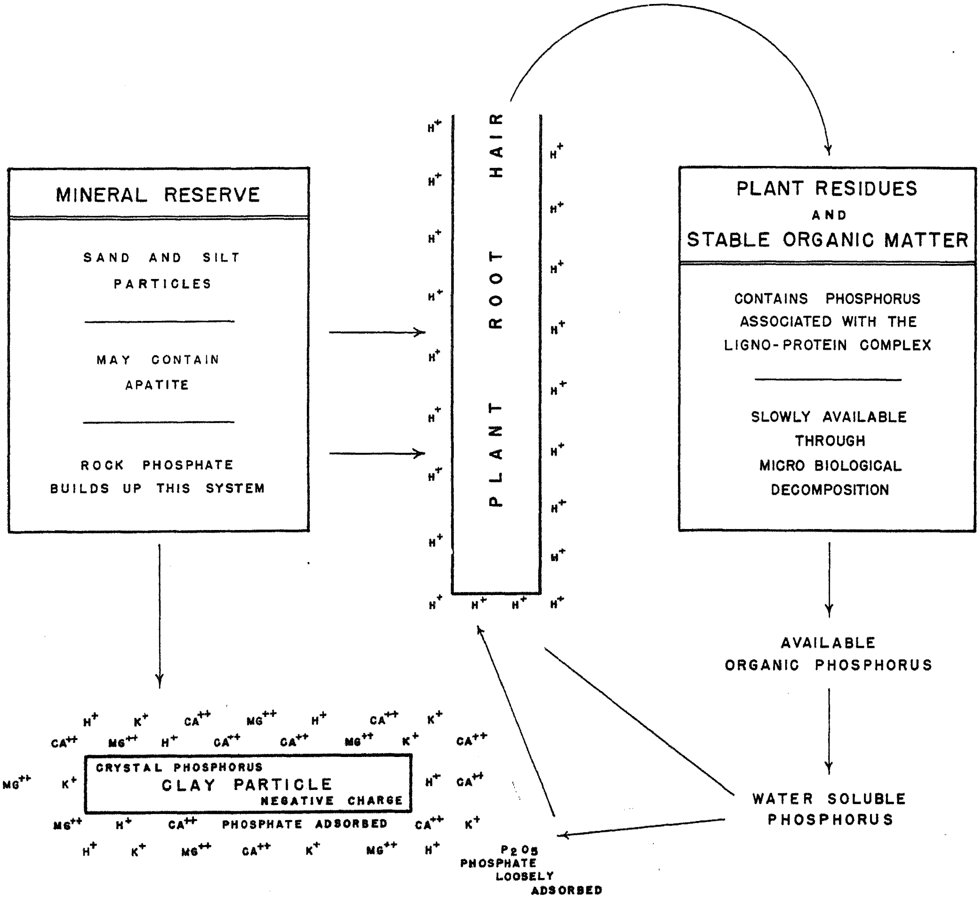

Figure 2.—Diagrammatic representation of some of the important forms of phosphorus in the soil.

a red filter, after adjusting the colorimeter to zero by using distilled water. Plot the transmittancy readings against the concentrations of the series of standard solutions. One mgm/liter of phosphorus is equivalent to 32 pounds of phosphate (P_2O_5) per acre (2,000,000 lbs. of soil).

Interpretation of tests for Soluble Phosphorus.—The chemistry of soil phosphorus presents a rather complex problem as illustrated in Figure 2. Phosphorus may be in the soil in many different forms, both organic and inorganic. Some of the organic forms such as the phosphorus contained in stable organic matter are relatively unavailable, while other organic forms are available. Phosphorus contained in the minerals of silt size may or may not be available, depending on the crop to be grown and the ionic saturation of the clay complex. The phosphorus associated with the clay particles may or may not be available, depending on the type of clay mineral and the degree of its adsorption by the clay. Water soluble phosphorus, that held in the intermicellular spaces of the colloid is usually available to most plants.

Early attempts to measure available phosphorus used such acids as weak sulfuric (9) dilute hydrochloric and citric (1). All of these proved to be rather successful. Some workers used slightly acid solutions of sodium acetate (7), which seemed to measure available phosphorus well on sandy soils. In the mid-west soils of higher clay content, the use of acid alone for extracting phosphorus did not always give good correlations between measured phosphorus and crop response to its addition as soil treatments. Many soils which had previously been treated with manure or superphosphate gave low acid-soluble phosphorus tests but showed little response to further additions of phosphate. It appeared that there was a source of available phosphate in soils treated with superphosphate and manure as well as in some virgin soils which was releasing to the plant some phosphorus not extracted by the acid. Bray (2), working on similar soils, has demonstrated that ammonium fluoride would replace the adsorbed phosphorus associated with the soil colloid by using the flouride in a rather dilute concentration (.03N) with hydrochloric acid (.1N). He was able to improve the relation between amounts of phosphorus so extracted and plant response to phosphorus treatments on the soil. The acid flouride extracting solution will sample part of the mineral reserve phosphorus, all of the water soluble phosphorus, and a portion of the adsorbed phosphorus. The slowly available organic matter phosphorus is not estimated by it. A given soil which would show a low 32#, (P_2O_5/A) phosphorus extract with acid flouride extracting solution will respond markedly to phosphorus additions. If 300# per acre of P_2O_5 can be extracted from a given soil area it is unlikely that this soil would respond to any phosphorus treatment other than starter phosphorus.* For additional interpretation data see Bray (2), and Klemme (6).

Soil pH

Procedure: Calibrate the glass electrode by using buffer solutions of pH 4.0 and pH 7.0. Be sure and allow the electrodes to soak

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*Additions of 12 to 30 pounds of P_2O_5/A near the seed would be considered starter phosphorus.

in distilled water for 15 minutes and also allow time for the instrument to become warm. For calibration procedure follow the outline furnished by the manufacturer of the particular instrument to be used.

Measure 5 gms. 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 bufers 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 film from the glass electrode, which will interfere with subsequent readings.

pH and Nutrient Ion Saturation.— There is a general relationship between pH and the percentage saturation by nutrient cations on some Missouri soils. Missouri soils, for example, having a pH of less than 4.8 are usually less than 50% saturated by bases or cations. When the pH is above 5.2 the saturation of the colloid by the total bases, i.e. cations other than hydrogen, is usually above 50%. However, experience has shown the pH measurement less reliable than the combined measurements of hydrogen, calcium, magnesium and potassium, which give a clear, accurate picture of the ionic saturation. About the only reason for making the pH measurement is to decide if the system is unsaturated enough by ions not giving acid reaction to warrant the determination of the total hydrogen. In some instances soils with a pH of 7.0 have shown the presence of some hydrogen. However, the amount is small, usually less than 1 M.E. per 100 grams. Soils showing a pH about 7.5 will contain practically no hydrogen.

Exchangeable Hydrogen (11)

Procedure: The same samples of soils used for the pH determinations are suitable for the determinations of total hydrogen. Calibrate the glass electrode of the pH meter carefully with a nitrophenol buffer (8 gms. para-nitrophenol, 40 gms. $Ca(CH_3COO)2.H_2O$ and .625 gms. Mg0 made up to 1000 ml. of distilled water with the solution adjusted to pH 7.0 by adding either HC1 or Mg0 as required) to a pH of 7.0. Add to the soil samples used in the pH determination 10 ml. of the nitrophenol mixture, stir thoroughly for 30 seconds and allow to stand for 30 mnutes. Stir again, insert the electrodes, shake the soil cup gently to insure contact, depress the switch and read the meter. Each change of one tenth in pH on going from 7.0 to 6.0 is equivalent to 1 M.E. of hydrogen per 100 gms. soil. (Should the sample show more than 10 M.E. hydrogen per 100 gms. soil) use 2.5 gms. of the soil sample and repeat the entire procedure in which case each change of one tenth in pH on going from 7.0 toward 6.0 would be equal to 2 M.E. of hydrogen per 100 gms. of soil.

Total Hydrogen and Ionic Saturation.—In humid regions the soil colloid is usually saturated predominantly with hydrogen, calcium, magnesium and potassium. Therefore each of these four ions must be determined in order to gain information as to whether the soil colloid is somewhere near ideal or badly out of balance from the point of view of being a suitable nutritional medium for plant growth. The sum of these four ions in M.E. will give a reliable index of the cation exchange capacity of the soil. Cation exchange capacity determined by the above method will result in a figure which is higher than the figures obtained by using the standard ammoniumacetate method since the measurements are based on di-valent ions. Once the cation exchange capacity has been determined then the per cent saturation of each cation may be determined. The following is an example showing the calculations a, b, c, and d obtained by using the values from a tested soil sample as given in A, B, C, D.

A. Exchangeable Calcium = 8.0 M.E./100 gms.
B. Exchangeable Magnesium = 2.0 M.E./100 gms.
C. Exchangeable Potassium = 0.2 M.E./100 gms.
D. Total Hydrogen = 6.0 M.E./100 gms.
Total exchange capacity = 16.2 M.E.
(a) 8/16.2 X 100 = 49.5 = per cent calcium saturation
(b) 2/16.2 X 100 = 12.3 = per cent magnesium saturation
(c) 2/16.2 X 100 = 1.2 = per cent potassium saturation
(d) 6/16.2 X 100 = 37.0 = per cent hydrogen saturation

The above sample may well serve to illustrate the following discussion. By studying the per cent saturation of a given soil by these four cations and correlating this information with crop response in the field, one would be able to determine if a given crop would grow well and if not what treatments should be used to change the soil so that it would grow the desired crop better. The results from Missouri soils show that the saturations of a soil by calcium and by potassium as given above, are too low to grow legumes satisfactorily, if at all. The amounts of calcium and potassium needed to bring about a favorable saturation will be discussed in detail later in the article.

Exchangeable Potassium

Procedure: Measure 10 ml. of the sodium nitrate extraction solution (250 gms. of $NaNO_3$ per liter) into a vial, add 5 gms, of air-dry soil (use a calibrated 5 gms. 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 of tap water temperature and cool. The temperature range of the water bath should be between 15° and 25° C. Measure 2 ml. of alcohol (95% ethyl or 1:1 isopropyl and amyl alcohols) in a colorimeteric 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 6 drops of a sodium cobalti-nitrite solution (50 gms. of $Co(NO_3)_2$ + 300 gms. of $NaNO_2$ and 25 ml. of glacial acetic acid made up to 1 liter). The cobalti-nitrite solution should be placed in the water bath and brought to the same temperature as 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 directing the stream against the side of the adsorption tube. After allowing the mixture to stand for 5 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 gms. 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: potash extracting solution, standard with 20 mgms. of potassium per liter of solution, and standard with 50 mgms. of potassium per liter of solution, into separate vials and cool in the water bath. (The standard potassium solutions should contain sodium nitrate in the same concentration as the extracting solution). To each of twelve clean colorimeteric adsorption tubes add 2 ml. of alcohol, 6 drops of cobalti-nitrite solution. Add forcibly with a medical syringe 2 ml. of the potash extracting solution to 4 of the adsorption tubes. Add forcibly 2 ml. of 20 mgm/L., potassium solution to four of the adsorption tubes. Add 2 ml. of 50 mgm/L., potassium 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 concentration of the solutions. The point on the curve for a concentration of 20 mgms/L is equivalent to .102 M.E. potassium/100 gms. of soil, or to 80 pounds potassium per acre. The point on the curve for 50 mgms/L is equivalent to .225 M.E./potassium/100 gms. of soil or to 200 pounds potassium per acre.

Degree of Potassium Saturation.—As for the change in degree of saturation of the soil by potassium, let us suppose that 78 pounds of this nutrient element per acre were added to the soil used in the previous example cited earlier. This would be an additional .1 of a M.E. per 100 grams ($.1/16.2 \times 100 = .6$ per cent) which would result in a potassium saturation of 1.8 per cent. In most instances this would be sufficient potash for a legume crop. The potassium saturation for the ideal growth of crops seems to be related to the type of clay making up the colloidal complex. Since the activity of potassium is relatively low on the kaolinitic clay colloid, the saturation on it by this element should be about 5 per cent or more. Since the activity of potassium on the montmorillonitic colloid is relatively high, its saturation on that kind of clay colloid may be as low as about 2 per cent. The values given Table 1 are suggested as a guide for the desirable potassium levels according to the total exchange capacity of the soil.

Table 1--Percentage Potassium Saturation Suggested for an Ideal Soil According to Exchange Capacity.

Total Exchange Capacity	Percent Potassium Saturation
4 M.E. per 100 gms.	9.00%
6 M.E. per 100 gms.	6.00%
8 M.E. per 100 gms.	4.50%
10 M.E. per 100 gms.	3.60%
12 M.E. per 100 gms.	3.00%
14 M.E. per 100 gms.	2.60%
16 M.E. per 100 gms.	2.25%
18 M.E. per 100 gms.	2.00%
All above 18 M.E. per 100 gms.	2.00%

Exchangeable Magnesium

Procedure: Place ½ ml. of the soil extract obtained in the potassuim tests in a colorimeteric adsorption tube. Add 4 ½ ml. of distilled water. Then add ½ ml. each of the following four reagents: A (8) [4.4 gms $Ca.(C_2H_3O_2)_2$ H_2O .37 gms. Al_2 $(SO_4)_3$ $4H_2O$ dissolved in 500 ml. of distilled water containing 10 ml. of conc. HCl made to 1 liter and then given an addition of 10 gms. of hydroxylamine hydrochloride]. B. (8) (2% soluble starch solution). C. (.033% thiazol yellow solution). D. (10% NaOH). Each reagent should be added with force to insure mixing. After the last reagent is added one vigorous shake is advisable to insure complete mixing. Use the green filter (540 mμ.) and adjust the colorimeter at zero with distilled water as the test liquid. With the standard curve for magnesium, convert the readings into M.E. per 100 grams or pounds per acre. Standard: The standard curve may be prepared as follows: Measure 5 ml. of each of the standard solutions containing 5, 10 and 20 gms. per liter of magnesium, in triplicate into colorimeteric adsorption tubes and then add to each tube ½ ml. of each of the magnesium reagents, A, B, C, and D. With the green filter in place, adjust the colorimeter at zero with distilled water as the test liquid, read the standards and plot the transmittancy readings against the concentrations of magnesium. Since this curve will not pass through zero at 100 per cent transmittance draw a straight line through the 20 and 10 points, then draw a line from 10 to 5 and extend it through the zero line. The magnesium solution containing 5 mgm/liter is equivalent to .83 M.E./100 gms. of soil or 200 pounds magnesium per acre.

Degree of Magnesium Saturation.—The magnesium saturation of the above soil used as an illustration was 12.3 per cent. In most instances any soil saturated with magnesium to 10 per cent has proved itself satisfactory for plant growth. However, soils with low exchange capacities containing less than .8 M.E. of exchangeable magnesium have responded to magnesium treatment even though they were initially saturated to 10 per cent by this nutrient element. As our knowledge of plant quality increases a more desirable figure for magnesium saturation of the soil may be obtained.

If it were desirable to change the magnesium saturation then 2000 pounds of high grade dolomitic limestone per acre would furnish 1 M.E. per 100 gms. of soil or 240 pounds of magnesium per acre.

Exchangeable Calcium

Procedure: Add 1 ¾ ml. of ammonium hydroxide (.5% solution) to the ¼ ml. of soil extract obtained in the procedure for phosphorus. Add forcibly from an automatic pipette 2 ml. of soap solution. (Shake 7.05 grams of oleic acid in a nearly saturated solution into 1.6 gms. of KOH in 5 ml. of distilled water, transfer this mixture to a flask. Use 50 ml. of 70% ethyl alcohol to make 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% 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 for complete development and then read on the colorimeter. Use the blue filter (420 mμ.) for the reading, and adjust the colorimeter at zero 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 mgms. per liter. Measure 1/4 ml. of each standard calcium solution, in duplicate into colorimeteric adsorption tubes and then add to each 1 3/4 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. For the reading use the blue filter, and adjust the instrument at zero with distilled water as the test liquid. Plot the transmittancy readings against the concentrations of the standard solutions. A concentration of 160 mgms. per liter is equivalent to 5.6 M.E. calcium per 100 gms. of soil, or 2240 pounds per acre; 400 mgms. per liter are equivalent to 14 M.E. calcium per 100 gms. of soil or 5600 lbs. per acre.

Degree of Calcium Saturation.—Lime added to the soil changes its percentage calcium saturation. Suppose 3 tons of ten-mesh, pure calcite lime were added to the above soil previously used as an illustration. This would theoretically be adding 6 M.E. of calcium and would change the calcium saturation from 49.5 to 86.5 per cent. Since the lime is not finely ground and therefore not immediately active this would not actually happen under field conditions. Before all the lime had completely reacted with the soil some of it would have been removed by leaching and lost through cropping. However, legumes would respond to this treatment and the soil would not be limed excessively. If the soil is to be plowed deeper than 6 inches, additional lime should be added according to the depth (usually 1/6 more for each additional plow inch is satisfactory). For the good growth of legumes the soil should be saturated with calcium to a degree varying from 65 to 85 per cent.

MODIFYING THE SOIL FERTILITY LEVEL BY SOIL TREATMENTS AS INDICATED BY THE SOIL TESTS

A study of the information given by the soil tests will reveal many differences in fertility level. Some of these are a result of the past years of particular practices in management, others are inherent to the soil body resulting from deposits of particular parent materials and of soil development processes. In some instances the modification of a particular fertility level may be accomplished in a rather short time. Other situations will require successive treatments of large applications of nutrient ions, along with a correct cropping system and proper tillage. A discussion of all the different situations which might occur would be too involved and beyond the scope of this bulletin. Nevertheless, since the understanding of certain soil tests is involved in the rate of modification of the fertility, some discussion is necessary.

Calcium-Magnesium Level

Soils which have recently been limed may quite frequently show the same acidity relationships as they did prior to this soil treatment. Because this situation may prevail, some investigators have questioned the accuracy of the tests of the soil for calcium or need for lime. In this case cited, the addition of lime has not modified the entire soil body enough so that the samples tested do not show the change on the test. In most instances it takes a period of from 4 to 5 years and several plowings and cultivations before the soil is sufficiently modified to make a sample show changes between testings. In some cases, lime applications have been made according to the soil test for a plow depth of 6 ½ inches,when actually the farmer may plow to a depth of 10 inches. In this case a soil test repeated a few years later will report but little modification of the soil. The fineness and purity of limestone become factors in reaction rate between soil and limestone. This can be observed by careful study of the information given by the soil test.

Phosphorus Level

In many instances it is extremely difficult to modify the phosphorus fertility level of soil. This fact has led to the use of high analysis phosphorus material, placed in bands so that it will be available in such a way as to give the crop roots contact with a concentrated area in the soil at some period of its growing season. Usually this practice has led to higher yields. In fact, the increase on such grains as wheat, oats and others has been as high as 100 per cent. However the fertility level of phosphorus in the whole soil body as tested may have been modified only very slightly. To draw a soil sample from a field treated with banded superphosphate so as to show any higher level than before treatment would indeed be a difficult task. When annual treatments of superphosphate are repeated over a period of years, the soil body usually becomes modified enough to reveal itself as a fertility difference. After 10 years of annual starter treatments (to some plots on the South Farm, in experiments on Putnam silt loam) the treated areas when tested, showed a mean of 35 pounds phosphoric acid per acre, while the untreated plots had only 16 pounds phosphoric acid per acre. This represents a change in the fertility level of phosphorus from what is considered "very low" to "low". Yet since phosphorus placement was practiced every year during this period the yields were satisfactory. The phosphorus level of soils can be modified more rapidly than the above figures indicate. A higher level (250 lbs. P_2O_5 per acre) has been found to be very desirable, when long rotations are to be grown, or where commercial nitrogen is to be used for high acre yields. Since highly available phosphorus is subject to rapid fixation, it would probably be more desirable to add the major amount of the phosphorus as rock phosphate and the smaller amount as superphosphate. Even if by using rock phosphate and superphosphate, one should modify the phosphate level of the plow depth to such an extent that it would test high, or 300 lbs. P_2O_5 per acre, it would still be well to continue adding small applications of 12-24 lbs. of P_2O_5 per acre of available phosphorus for small grains and corn. There are two good reasons for the recommendation of the above practice; first, one will be able to maintain a high phosphorus level, and second, the combination of calcium-acid-phosphate and calcium sulfate found in superphosphate are excellent from the environmental point of view in supporting emergence and survival of the plant. "Starter" phosphate, as these continued applications would be called, have given superior stands on the soils of highest fertility level. Whenever conditions have been slightly unfavorable, mixed materials, such as 4-12-8, 3-12-12, 8-8-8 and 4-24-12, make excellent starter fertilizers for high percentage of emergence and survival for seedings of common farm crops.

Potassium Level

The level of potassium found in a soil is one of the best indications of past soil management. A low test for potassium is usually found wherever crop residues have been removed for many years. The reverse is usually true, namely, the potassium level will be reported high by the soil test when residues and farm manure are added to the soil regularly.

Seasonal variation in potassium tests have been recorded many times. Samples which are taken in the fall before frost are frequently 50 to 100 lbs. lower than they will be in the spring. This is because the plant residues such as roots, stems, leaves, etc., contain potassium which is returned to the soil during the winter months. Therefore the date of sampling is an important factor in understanding and interpreting the potassium levels.

The practicability of trying to change a soil with low potassium to a high one through a single heavy application of it is somewhat debatable. In many instances it seems more advisable to bring the potassium level up more slowly by making frequent applications of smaller amounts of potash materials and by returning more of the plant residues. However, in instances where bulky residues, such as an alfalfa crop, are difficult to return, large amounts of potash materials may be added to the soil if they are plowed in deep and mixed well with a large volume of soil. Heavy applications of muriate of potash (200 to 400 lbs./A) to the surface soil or as starter applications are to be avoided because this fertilizer salt will retard germination and emergence of the seeds. However, small amounts (200 lbs. to 400 lbs.) of mixed fertilizers with high potassium contents such as 3-12-12, 4-24-12 and 8-8-8 used as starter are highly desirable on soils of medium to high potassium levels. In fact on flat poorly drained soils high potash starters are very desirable for corn even on soils which test high in potassium. The principle explanation for this observation appears to be that whenever wet soil conditions are encountered, the roots do not penetrate rapidly into the lower soil depths, hence require an abnormally high potassium level in the surface. This response to potassium has been referred to by the British as "cloudy weather" response to potassium.

Effective Soil-building Programs Must Be Test-Guided

Though in scientific work emphasis goes on having only one variable at a time, one can't be content to think of only one factor of soil fertility as responsible for good crop growth. Therefore in soil testing we are coming to see a list of several elements that might be deficient. For years lime for its calcium was considered as the only shortage in soil fertility. Nitrogen has also been deficient in many soils. On other soils thought went to only phosphorus. More than one fertility shortage must be considered for growth of bigger crops now that our soils have been under intensive cultivation longer. All of the essential elements must be considered as a group instead of only one at a time. They have influences on each other and their final effects are not mere additions of individual helps. It is essential that we see the larger picture and soil testing is helping to elucidate this.

Unless calcium and magnesium are kept within certain ratios they are not so efficient. Phosphorus serves best when present in the soil in amounts as those of certain relations to the calcium, and those of the nitrogen and those of the hydrogen. Interreactions of other elements is suggested. All this suggests that testing for the gross deficiency and remedying a single item is not enough. This remedy must be considered in relation to the amounts of each other fertility element in the soil. Soil testing is now simple enough to test for many elements quickly, and includes a good number of essential elements, namely nitrogen, phosphorus, potassium, calcium and magnesium. Unfortunately there are still many elements for which tests are not effective.

The trace elements manganese, boron, copper, zinc, molybdenum in the soil and others are in this category. There is hope that tests for these will eventually be worked out. All of this points out that of the soil factors in crop production, soil testing measures many but by no means all. While progress has been made much unknown is still left for later soil research to reveal. Not only the soil as a supply of fertility and all the chemical activities by it, but the crop's growth activities also are factors in production. Roots are not confined, but move through the soil. More roots or less roots per unit of soil according as crops differ in this respect, deeper-going roots in contrast to shallow roots, and roots rich in protein as compared to those less so, are all plant factors entering in to modify the interactions between the plant's root system and the fertility on the colloidal complex of the soil.

Progress has been made by soil testing as a chemical technique, and by its use in laboratories in the counties or as a test kit in the field. It is going out to the farmer who is adding his observations to the solution of his problem and is depending less on help from others. Soil testing is making the subject of soil fertility farmer's talk and no longer only technical terms. As more farmers can be helped by soil testing to diagnose their own soil fertility shortages, they are closer to the solution of the problem of building up the soil for better production as yields per acre and as feed quality of the products. Evidence is plentiful from research projects to tell us that the fertility of the soil is a declining resource, but until the chemical soil tests help more farmers to estimate the fertility levels in their soil there will not be enough appreciation of that serious fact to get much done about it.

The extensive use of limestone and other fertilizers, all growing enormously in tonnages each year are testimony that Missouri farmers are going forward not only in conserving the soil but in building it better in many instances. Chemical testing of the soil is one of the helps designed to make this task of maintaining the fertility of the soil more widely understood and to get it more widely accomplished.

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TABLE OF CONTENTS