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Chemical Soil Diagnosis By the Universal Soil Testing System

(A Revision of Bulletin 392)

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DURING the past ten years numerous methods have been devised or improved for the purpose of evaluating the chemical status of the soil with respect to the nutrition of plants by means of rapid, simple soil tests. This Station has issued several publications in this field. The earliest of these, Bulletin **333,** "Microchemical Soil Tests", issued in January, 1932, (35) was the first to propose tests for nitrate and ammonia nitrogen, calcium and aluminum, in addition to the phosphorus test, in order to obtain some measure of the interdependence of various chemical factors involved in soil fertility. These methods were revised and amplified so as to provide for the simultaneous testing for various constituents from a single soil extract. The "Universal soil extracting solution" employed in these tests was first introduced as a mimeographed supplement to Bulletin **333,** issued in February, 1933 (36). The methods in substantially their present forms were described in detail in Bulletin **372,** "The Universal Soil Testing System", issued in 1935, (37) and in Bulletin **392,** under the same title, issued in 1937 (38). Circular **127,** "Soil Testing Methods — The Universal Soil Testing System", issued in 1939, (39) is an abbreviated description of the methods, without the useful charts included in the earlier publications, now no longer available for distribution.

During the past five years the soil testing methods developed at this Station have become extensively used for practical chemical soil diagnosis, not only in Connecticut, through its service testing by the Extension Service of the University of Connecticut, and by this Station at New Haven and Windsor (Tobacco and Vegetable Field Station), but in many other states and in numerous foreign countries.

Agricultural services in Great Britain have been employing these methods extensively in their campaign for growing more food. The war efforts of our own country now demand increased crop production for ourselves and our allies with less available farm labor. The supply of many fertilizer materials will be curtailed. Ships, trains, and trucks moving fertilizers toward the farm are needed for the transportation of vital war supplies. The competent employment of soil testing will do much to promote greater efficiency in the farmer's part in winning this war.

SOIL EXTRACTING SOLUTIONS FOR RAPID CHEMICAL TESTS

THE earlier methods of chemical soil study for fertility evaluation were based on analyses of solutions resulting from the treatment of the soil with strong solvents, such as concentrated mineral acids. Practically inert sand and silt particles and humus residues were more or less completely broken down. The results of such analyses were of great value in revealing the fundamental constitution of the soil as affected by soil-forming processes. However, they failed to show any consistent differences between soils that were known to vary widely with respect to the responses of crops to various chemical treatments, such as fertilizers, manures and lime.

Extractions of the soil with solutions of less drastic solvent power. such as the 1 percent citric acid employed by Dyer (13) and the fifth normal nitric acid of Fraps (22), have been used by numerous soil chemists for many years in detailed laboratory procedures. On some soils each gave good correlation with crop results, while on others the results were not satisfactory. Citric acid tended to attack the iron and aluminum of acid soils to too great a degree, while the dilute nitric acid was diminished in solvent power by neutralization due to dissolved bases in soils containing carbonates. The methods were too expensive in laboratory time and equipment to be suitable for general application in soil diagnosis, even when the results were considered to be of practical benefit.

At first thought, the natural solvent to which soils are subjected in nature would seem to be pure water. However, the liquid that bathes the soil particles in a moist soil in the field is more or less charged with carbonic acid, as well as small but significant amounts of various mineral and organic acids, more or less buffered with salts resulting from interaction with the soluble constituents of the soil. The contact of the rootlets and root hairs with the colloidal particles of the soil provides a mechanism for the absorption of chemical elements by plants that can now be explained to a degree as a result of recent expansion of knowledge concerning colloidal interface phenomena. No one artificial solvent, acting upon the soil for a few minutes to a few hours of time, can hope fully to duplicate all the conditions involved in the ability of the soil to provide properly for the chemical nutrition of the crop.

Thus it must be emphasized at the outset that any chemical method of soil extraction is quite empirical in character, and the results at best can give only approximate quantitative expression to beneficial or harmful concentrations of various chemical constituents that are most likely to be prevalent in the active soil-plant system.

Most laboratory methods of chemical soil analysis are based on the washing from the soil of practically all of the constituents capable of being removed by the action of a given solution. Quick chemical tests must necessarily rely upon the results of an incomplete extraction wherein the interaction between the extracting solution and the soil is permitted to continue for but a few minutes, and only a portion of the extract is removed from contact with the soil. This might be considered a serious limitation. However, it is a condition somewhat analogous to the crop itself as a soil extractant. This may be a factor in the apparently greater practical value of "quick test" results as compared with those from the more detailed soil analyses.

The various quick test methods that have been developed during the past few years may be classed in four general types with reference to the soil extractant.

The first of these involves solvent action of the same order of magnitude as pure water. The very dilute acetic acid (.025 N) of Spurway (45) in his general procedure falls in this category. Fully soluble soil constituents, such as nitrates and chlorides, are readily measured. Soils of very high chemical fertility, such as intensively fertilized greenhouse or garden soils, may also contain quite measurable amounts of strictly water-soluble phosphorus, potassium or other constituents usually not extractable from field soils in amounts that can be distinguished by simple testing reagents.

A second type of extractant consists of a neutral salt of fairly strong concentration (usually greater than half-normal). The 25 percent sodium perchlorate solution proposed by Bray (7), and the normal ammonium acetate solution used by Peech (41) in micro methods, are of this character. Such an extractant removes bases from the soil through the mechanism of base exchange, in addition to the water-soluble constituents. However, a neutral salt extraction fails to liberate measurable amounts of phosphorus, aluminum, and iron that are capable of dissolving under the slightly acid conditions that exist in most natural soil solutions.

A third type of extractant is employed in quick test methods most commonly used in the Middle West. A strong mineral acid, such as hydrochloric, nitric or sulfuric acid, is employed. This is necessarily in dilute concentrations, usually less than half normal, in order to prevent the dissolving of mineral particles or humus substances that are only slightly attacked under natural soil conditions. The acid solution is frequently buffered at a given pH, such as 2.0 or 3.0, by the addition of a neutral salt. The total acid concentration is weak, in the sense that it may be readily exhausted by the neutralizing action of amounts of lime or other basic materials frequently existing in soils. On the other hand, the hydrogen-ion concentration existing at a pH of 2.0 or 3.0 exerts a strong solvent effect upon difficultly soluble minerals, particularly upon apatite or phosphate rock particles. Such solvents dissolve some potash and other bases in addition to the water-soluble and absorbed forms. However, it is difficult to confirm this on non-calcareous soils under quick test conditions, since only a partial extraction is effected. Carbonates are actively decomposed by the strongly ionized acid; hence calcium and magnesium tests on calcareous soils include quantities of these bases that may be considered part of the insoluble base reserve, rather than actively affecting the soil-plant system.

Methods employing such soil extractants are as follows:

Truog (51) original phosphorus procedure, using .002 normal sulfuric acid, buffered at 3 pH with ammonium sulfate.

"Truog-Hellige" commercial set (25), using dilute hydrochloric acid, buffered with a salt.

Bray (5), Thornton (49) and Emerson (15) phosphorus tests; also the "Hi-lo-fos" and "Sudbury" phosphorus tests, using hydrochloric acid (0.7 to 0.8 Normal) and ammonium molybdate.

Bray (6) potash test, using nitric acid and sodium acetate.

Spurway (46) outlines tests for "reserve" phosphorus and potash, using 0.135 Normal hydrochloric acid.

Baver and Bruner (2) soil testing methods, using 0.3 Normal hydrochloric acid.

Miles (31) tentative procedure, using a buffered perchloric acid extractant.

A fourth type of extractant employs a weakly ionized organic acid buffered with its sodium salt. A mixed solution of acetic acid and sodium acetate is now most extensively used as the soil extractant for quick chemical tests. As introduced by the writer (37), under the designation of the "Universal soil extracting solution", it is approximately 0.5 Normal in total acetic acid concentration and is buffered at approximately 4.8 pH with sodium acetate. Hester (26) adopted a solution modified from that used in a laboratory phosphorus test independently proposed by Dahlberg and Brown (11) appearing later in the same year (1933) as the writer's original use of this type of extractant. Hester's solution is more dilute, with a total acetic acid concentration of approximately 0.2 Normal, buffered at from 4.8 to 5.0 pH. Merkle (32) gives soil testing procedures based on the original Dahlberg and Brown extractant, of approximately twice the strength of that of Hester. Fink (20) reports using the Universal soil extracting solution modified by the addition of a sufficient amount of hydrochloric acid to bring it to 3.0 pH. Such an extractant is probably intermediate in solvent power between the third and fourth types of extractants described herein.

The Egnér (14) lactic acid-calcium lactate extracting solution, now frequently used in laboratory procedures abroad, is similar in principle to the acetic acid-sodium acetate extractants. The chemicals do not lend themselves so readily to employment in quick test methods.

Other extractants proposed for use in quick test methods include the 0.1 Normal acetic acid of Harper (24) and the 1 percent potassium carbonate of Hockensmith, Gardner and Goodwin (28), both employed for phosphorus tests.

Some investigators have proposed the idea of measuring the absorption of phosphorus or potash, or both, by a given amount of soil from solutions containing known concentrations of these constituents. Emerson (15) proposed such an absorption method for potassium. This has been applied in the Sudbury commercial soil testing set. Purvis and Blume (42, 43) have developed a method for both phosphorus and potassium based on this principle. Such procedures may give valuable information when used in correlation with direct methods.

THE UNIVERSAL SOIL EXTRACTING SOLUTION

THIS solution, of the fourth type previously discussed, was selected by the writer on the basis of the following characteristics:

1. It is buffered at a hydrogen-ion concentration closely approximated by that of aqueous solutions saturated with carbon-dioxide in concentrations normally existing in soil air, or of weak plant root acid secretions. This degree of acidity is readily attained by most soils in humid regions.
2. Its solvent action is practically unchanged by contact with the soil. Its total acidity and buffer capacity are sufficient to prevent a change of more than 0.2 pH on prolonged contact with a soil containing the equivalent of 2.5 percent of calcium carbonate, using the proportion of soil to extracting solution here employed.
3. The resultant soil extract permits the development of the color and turbidity reactions for the various tests with a minimum of manipulation.
4. The ions present in the extracting solution do not interfere with the tests for the constituents to be determined.
5. The resultant soil extract contains concentrations within the range of sensitivity of the various tests, for all normal agricultural soils.
6. Turbidity or discoloration of the extract thus obtained is not sufficient to interfere with the tests, except in extreme cases.
7. Tests of soil extracts made with this solution are in harmony with known crop performance over a wide range of soils.
8. The solution does not become contaminated by biological decomposition.

During the past eight years, the writer has carefully studied tests of soil extracts obtained by this solution on many soils, not only from Connecticut, but from many states, and from areas in the American tropics. Concepts involved in the interpretation of the tests must necessarily vary under different soil and climate conditions and for different types of crops. Although the methods herein described were first developed for conditions existing in southern New England, it is now confidently believed that they serve to give useful information concerning almost any soil that may be thus examined.

As chairman of the Sub-committee on Soil Testing of the General Fertilizer Committee, American Society of Agronomy, during the past five years, the writer has studied the independent results of numerous collaborators on a series of 31 check soils from 15 states east of the Great Plains area, assembled by the sub-committee. In its recent report (40) there has appeared to be a consistent difference in relative results on a few soils between methods using the Universal and other acetic acid-sodium acetate extractants from those using dilute solutions of the stronger acids. Certain silt and clay loams of the Corn Belt give lower phosphorus and potassium tests by the former type of extractant, while the higher results by Thornton, Truog and similar methods appear more in line with the "case history" of the soils in question. On the other hand, the latter methods have given inconsistently low tests for phosphorus on a highly calcareous soil and somewhat higher phosphorus and potassium tests on a few other soils than are indicated by field responses to treatment. Of most significance is the general agreement in relative results, for a given constituent, irrespective of the type of extractant used in the various quick test procedures, when the data are obtained by a skilled operator.

Certain modifications in procedure for adapting the tests to special soil conditions will be indicated in the presentation of the details of the methods.

THE SOIL SAMPLE

THE interpretation of soil tests must be based on an assumption that the sample actually tested is truly representative of the conditions existing in the particular layer of soil and position with respect to the plant roots or fertilizer placement existing in the given area of ground in question. A large field, planted to one crop, that has been of uniform past production and soil treatment and that is apparently a single soil type, may possibly be represented by a single test sample, comprising a careful mixture of numerous borings or soil slices of uniform thickness through the depth of the plowed zone (usually 6 to 7 inches) well distributed over the field. However, in many cases, several separate composite samples from differing portions of the field must be examined. Samples from portions of a field that show definitely poorer or better results than the average, not readily explainable on the basis of obvious physical soil differences, should be compared with the samples from areas of normal production. Permanent grass turf, such as pasture sod, should be sampled to the depth of only 2 inches if any treatment that might be used must be applied as a top-dressing. Separate samples from two or more soil depths may reveal significant information. No simple rule for soil sampling will apply to all cases. Common sense is the best guide, bearing in mind that in the final mixed portion actually subjected to test is only a spoonful from an area of land usually representing thousands of tons of soil.

Instructions for those who collect and submit their own soil samples for testing in Connecticut, as issued in Circular **131,** "Soil Testing in Connecticut", are as follows:

The soil sample should be a thorough mixture of equal amounts of soil collected at 20 or more points well distributed over the field or area in question. Vertically cut shovel or trowel slices of uniform thickness, or borings, should be taken. For cultivated soils, sample to the depth of 6 inches. Permanent sod, as in pastures and lawns, should be sampled from the upper 2 inches. If desired, separate samples of soil from lower depths may be made. Mix the soil thoroughly, and remove stones, coarse roots or hard clods. Each sample should be packed in a clean carton, box or bag not previously used for drugs, chemicals or other contaminating substances. An unused half-pint ice cream carton is quite desirable. The County Farm Bureaus supply suitable mailing tubes. Each sample should be marked by number, name of field, or other identifying legend.

If there are distinct types of soil in the field, or important differences in past treatment or crop growth, separate samples should be submitted.

Soils are received for testing at the following laboratories:

Agronomy Department, University of Connecticut, Storrs
Tobacco Substation, Windsor
Soils Department, Connecticut Agricultural Experiment Station, New Haven

Record sheets, letters or notes accompanying samples must indicate *the crop or crops involved,* and as much as possible of the following information:

1. Land surface (whether hilly, rolling or level).
2. Drainage, either natural, or as improved by tile or ditches.
3. Underlying formation, whether "hardpan", sand, gravel or rock.
4. Special soil features such as mellowness or hardness, tendency to erode, unusual shallowness of soil, stoniness, etc.
5. Crops grown in past few years, and description of any abnormal results not caused by other factors.
6. Soil treatment with respect to lime, manure, fertilizer, etc., in recent years.
7. Approximate area represented by the sample.
8. Amount and kind of manure available for soil improvement.
9. Description of all unusual conditions.

When the samples are brought to the laboratory, most of this information may be given orally.

Time of sampling: The soil is a dynamic body, teeming with micro-organisms whose activities vary from day to day and from season to season with changes in temperature, moisture and food supply. Nitrate and ammonia nitrogen contents of the soil are especially variable, as will be discussed in the section on test interpretations. A rapidly growing crop depletes some of the active constituents of the soil. For this reason, at the end of the growing season, soils show high tests for nitrates and potassium only when the amounts of these constituents added in the fertilizer, or becoming available in the soil, are in excess of crop demands. There are also seasonal fluctuations in soil acidity, which influence the availability of plant nutrients to some extent. Acidity is normally at a minimum in early spring, and at a maximum in midsummer.

All of the above factors must be taken into consideration in the interpretation of the tests. For general soil diagnosis, tests on samples taken in early spring are most reliable. However, soils studied during the growing season give tests most closely related to the performance of the crop, and are particularly valuable in determining immediate need for supplemental fertilization. Tests in the autumn, after the crop is harvested, best indicate whether or not the fertilizer has been in excess of crop needs. Thus the choice of time when the sample is to be taken depends upon the purpose for which the test is made.

Preparing the soil sample for testing: The field-collected sample, upon receipt for testing, is usually more or less moist. If too sticky to be screened, it should be dried to a mellow-moist condition. After mixing the entire sample, a portion of suitable size (usually about 100 cc.) should be screened with a 2 mm. or 10-mesh sieve to remove stones, gravel or coarse roots. The screened sample, further mixed, should be tested as quickly as possible, preferably before loss of all of its field moisture. Samples reserved for future testing should be promptly air-dried, and stored in containers with tight covers, in a place that is free from strong laboratory fumes, particularly ammonia or acid vapors.

SOIL REACTION (pH) TESTS

SOIL reaction, in terms of the pH scale, is now generally accepted as one of the most important single factors involved in the chemical fertility of soils. Knowledge of the degree of acidity or alkalinity is almost essential in the proper interpretation of the results of the other chemical tests, especially those for phosphorus, calcium, magnesium, aluminum and manganese. The pH test is necessarily a separate measurement from the tests that are applied to the soil extract in the Universal soil testing system. Most laboratories or testing centers that conduct several hundreds or thousands of tests each year find it desirable to make the pH tests by electrical apparatus. Several reliable commercial pH meter sets using the principle of the glass electrode are now on the market. These instruments enable a skilled operator to make accurate pH measurements on hundreds of soils in a few hours. The quinhydrone electrode type of instrument is still frequently used with good results, but is subject to considerable error on certain soils, particularly those containing oxidizing materials, such as manganese dioxide.

When soil testing is not conducted on a sufficient scale to justify the purchase of electrical equipment, the measurement of pH may be done colorimetrically by the use of indicator dyes. A procedure that has been successfully used by many persons during the past 15 years is the one developed by the author (33) and described in Bulletin 333 of this Station. Since this publication is now out of print, the details of the method are outlined here.

The Morgan pH testing set: The technique employed involves the use of a special porcelain block, as illustrated in Figure 1. This facilitates the operation of extracting the soil without the resultant color due to turbidity from the soil itself. The soil is placed in compartment "B", on the lower side of the perforated partition. The surface is pressed gently with a clean knife, or spatula, to prevent the possibility of open channels through the soil mass, and leveled off with the sloping face of the block. The narrow channel "C" and test cup "B" should be wiped clean of soil particles. If desired, a small dam of clean, coarse quartz sand of high purity may be poured in at the upper end of channel "C" at the lower edge of the soil mass. This is especially useful on silty soils that tend to flow down the channel upon saturation with liquid.

An extracting solution, prepared by dissolving 3 grams of sodium chloride, of analytical reagent purity, in 1 liter of distilled water, may be employed. It is also feasible to use the indicator solution itself as the soil extractant, except on soils that absorb the color from the dye, or that tend to give a turbid extract. The extracting solution, or indicator solution, is added to compartment "A", above the perforated partition, drop by drop, until the soil mass becomes saturated and liquid begins to trickle down the channel into the test cup "D". Uniform flow along the channel may be guided by the tip of a clean tinned paper clip or glass rod.

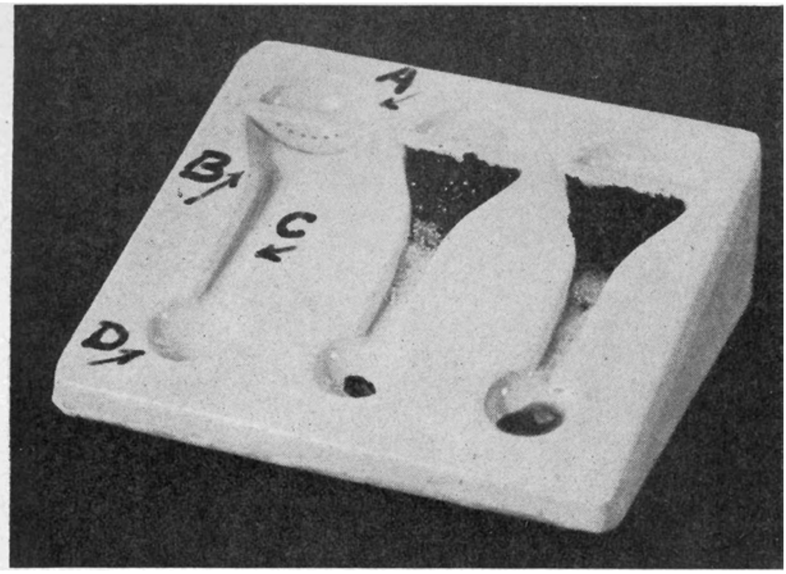

FIGURE 1. Morgan Soil Test Block used in colorimetric pH test technique. Compartment "A" for addition of liquid extractant, separated from soil in compartment "B" by a perforated partition; channel "C" for flow of extract into test cup "D".

If the extracting solution is used, the indicator solution should be added to the test cup before the extract flows into it. A half-drop quantity, obtained by touching the tip of the indicator transfer pipette or eye-dropper to the bottom of the cup and squeezing out a bead about three-eighths inch in diameter, should be used. When the liquid of a uniform color fills the test cup, it is compared with the color chart for the particular indicator[1] used in that section of the block.

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[1] The color charts, test blocks and indicator solutions may be obtained from the LaMotte Chemical Products Company, Baltimore, or the Fischer Scientific Company, New York.

The test block supplies three testing sections, for simultaneous extraction and use of the three indicators, as follows:

INDICATOR	RANGE
Bromthymol blue (0.04%)	6.0 - 7.6 pH (slightly acid to slightly alkaline)
Chlorphenol red (0.04%)	5.0 - 6.6 pH (moderately to slightly acid)
Bromcresol green (0.04%)	3.8 - 5.4 pH (strongly to moderately acid)

One of the above three indicators is almost certain to cover the proper range for any soil in the humid section of the country. In arid regions, where alkali soils occur, or for extremely acid peaty soils, other indicators may be selected, such as the following:

INDICATOR	RANGE
Cresol red (0.04%)	7.2 - 8.8 pH (slightly to moderately alkaline)
Thymol blue (0.04%)	8.0 - 9.6 pH (moderately to strongly alkaline)
Bromphenol blue (0.04%)	3.0 - 4.6 pH (extremely to strongly acid)

These indicators are conveniently used from one-ounce bottles with screw cap dropping pipette caps.

The indicators should be of a color approximating the mid-color of their range. In bottles, indicators may gradually become more alkaline through contact with the glass. Thus the bromthymol blue may become deep blue, or chlorphenol red may become violet red. In such case, dilute hydrochloric acid (1 to 20) may be added to the bottle, drop by drop until the proper color is restored.

In case charts are not available, the approximate colors developed by the most commonly used indicators, in relation to pH, are as follows:

pH and Color

INDICATOR	3.8	4.2	4.6	5.0	5.4	5.8	6.2	6.6	7.0	7.4
Bromcresol green	yellow	greenish yellow	green	blue-green	blue	——	——	——	——	
Chlorphenol red	——	——	orange red	orange	salmon	red	violet red	——	——	——
Bromthymol blue	——	——	——	——	——	yellow	greenish yellow	green	blue-green	blue

Other colorimetric pH methods: A technique that has come into frequent use in recent years involves the use of barium chloride as a clarifying agent. The test is conducted in test tubes or glass vials.

A suggested procedure is as follows: Place a teaspoonful of soil, one-fourth teaspoonful of powdered barium sulfate ("X-ray purity" reagent) and 10 ml. of distilled water in a one-half ounce glass vial. Stopper with a clean cork and shake thoroughly. Let the vial stand until the upper third of the contents has settled clear. Add 1 drop of the indicator solution and stir the supernatant liquid gently, taking care not to roil the settled portion. The resultant color should be compared as indicated for the previously described procedure.

The above method is especially useful on heavy soils that tend to yield turbid extracts or that are too impervious for the application of the Morgan test block procedure.

A number of inexpensive simple field pH kits are also on the market. These give the approximate pH of the soil, usually to within 0.4 pH of the results obtained by the best laboratory methods, which is often sufficiently close for practical purposes.

The pH test is not a direct measure of the amount of lime that is desirable to apply in the correction of an acid condition. However, when the texture and humus content of a soil are taken into consideration, the pH serves as a practical guide to lime use. This is discussed in a later section on "Interpreting Soil Tests".

SOIL EXAMINATION FOR PHYSICAL CHARACTERISTICS

Soil Texture

SOIL texture, involving the relative proportion of sand, silt and clay in the soil, is an important consideration in the proper interpretation of quick chemical tests. A definite measure of soil texture is obtained by mechanical analysis. A useful method, giving satisfactory practical results on most soils, is the hydrometer technique devised by Bouyoucos (4). However, it is usually impractical to make such measurements on the large numbers usually involved in quick test operations. As a rule, the texture of the soil can be fairly assessed by a skilled observer, chiefly on the basis of the feel of a moderately moist soil when rubbed gently between thumb and forefinger. A few simple rules are helpful in this connection, for characterizing soils of the more common textural classes.

[redacted]

Loamy sand: harsh, gritty feel; very slight tendency of the moist soil to stick together when pressed.

Sandy loam: definitely gritty; may be pressed into a soft mass, if moist.

Fine sandy loam: mellow and only moderately gritty feel; may be pressed into a firm mass, if moist.

Loam: mellow, moderately smooth feel; moist soil may be lled into firm rods; not perceptibly sticky.

Silt loam: Smooth and "floury" feel; moist soil only slightly sticky; readily rolled into firm, slender rods.

Clay loam: Very smooth, "slippery" feel; definitely sticky when moist; easily modeled into any shape.

A more detailed description of soil textures has been published in Bulletin **423** of this Station, pages 8 to 11.

Organic Matter

Some evaluation of the organic matter content of a soil is also essential to the proper interpretation of soil tests. A number of soil testing laboratories make some measurements of organic matter as a supplement to the quick test procedure. A reliable, reasonably rapid technique is the Turin (50) modification of the Schollenberger (44) dichromate method, also outlined recently by Merkle (32). Thomas and Williams (47) employ an abbreviated adaptation of the Schollenberger method, involving only partial decomposition of all of the organic matter.

Some soil testing laboratories estimate organic matter content from the loss effected by igniting the previously oven-dried soil at full red heat to constant weight. Loss-on-ignition is a useful soil measurement. However, it gives values of much higher magnitude than can be ascribed to the organic matter content, particularly on loamy or clay soils relatively low in humus, due to the volatilization of chemically combined water and certain inorganic elements. Such a procedure is most satisfactory when soils of similar textural type are being compared.

Persons who are familiar with the color of the soil at various organic levels can usually make a fair estimate of organic matter by observation. It must be borne in mind that the dark color imparted to the soil by humus is deepened by moisture; also, that a sandy soil is much darker at the same organic content than a heavier soil. Under Connecticut conditions, approximate colors of moderately dry soils, at varying organic levels, are approximately as follows:

Color Range and Organic Content

Soil texture	Brownish yellow, reddish yellow, or light gray	Light yellow brown, light reddish brown or light gray brown	Medium brown or medium grayish brown	Dark brown or dark grayish brown	Very dark brown or gray black
	%	%	%	%	%
loamy sand	minus 0.5	0.5 - 1.0	1.0 - 2.5	2.5 - 4.0	4.0 plus
sandy loam	minus 0.7	0.7 - 1.5	1.5 - 3.0	3.0 - 5.0	5.0 plus
fine sandy loam	minus 1.0	1.0 - 2.0	2.0 - 4.0	4.0 - 6.0	6.0 plus
loam or silt loam	minus 1.2	1.2 - 2.5	2.5 - 5.0	5.0 - 7.0	7.0 plus
clay loam	minus 1.5	1.5 - 3.0	3.0 - 6.0	6.0 - 8.0	8.0 plus

In prairie regions, soils are usually darker at the same organic matter content than indicated in the above scheme.

DETAILED DESCRIPTION OF THE UNIVERSAL SOIL TESTING METHOD

General Plan

THE filtered extract obtained from soil treatment with the Universal soil extracting solution or other extractant is tested for various constituents by transferring small quantities, usually from 1 to 10 drops, to either a porcelain or glass spot plate, with depressions holding approximately 20 drops, or to small glass vials of uniform size (50 mm. by 10 mm.), followed by the addition of appropriate reagents for the development of color or turbidity tests. The general plan of such micro-chemical tests follows the general technique for micro-chemical tests most extensively developed by Feigl (18, 19). Application of such procedure in quick chemical soil testing was first reported by the author in connection with the nitrate test (34).

Chemical tests of such a nature must be conducted with reagents that are sensitive to approximately the same concentrations of the constituent in question, irrespective of the presence of other elements or ions that are likely to be present ni the soil extract. When some other constituent interferes by giving a similar test or by increasing or decreasing the sensitivity of the test, the extract must be purified by some chemical technique designed to remove or inactivate the disturbing substance. This may be accomplished in a refined laboratory method, but is not ordinarily practicable in quick test procedures.

Equipment

The following list itemizes the equipment normally required for conducting the usual routine tests. Specifications are those that have been found most generally desirable, and the tests are calibrated on the basis of their use. A sufficient quantity of glassware, etc., is provided for testing six soil samples at the same time.[1] For larger operations, the numbers may be increased.

1 Supply bottle, 1 liter or larger capacity, for soil extracting solution.
1 Cylinder, or burette, graduated, 10 ml.
1 Spoon, measuring, teaspoon size.
1 Block, wooden, with 6 holes of ¾ inch diameter, for supporting filtering tubes.
1 Block, wooden, with 12 holes of ½ inch diameter, for supporting test vials.
1 Filter paper, box of 100 sheets of 9 cm. diameter, C. S. and S. 597 (American manufacture), Munktell No. 0 or similar grade.
6 Tubes, soil filtering, 15 mm. inside diameter, with funnel mouth 35 mm. diameter and air vent (or separate tubes and funnels of similar dimensions).
6 Pipettes, eyedropper type, with unflattened straight tip of 2 mm. diameter, or transfer pipettes graduated to 0.05 ml.
6 Rods, glass, 100 mm. by 4 mm.
12 Vials, glass, 50 mm. deep, 10 mm. inside diameter.

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[1] Arrangements have been made with the LaMotte Chemical Products Company, Baltimore, Maryland, for supplying assembled sets of the above equipment and commercially prepared extracting solutions and reagents to those who desire this service.

2 Spot plates, white porcelain, sets of 12 depressions of 20 mm. diameter and 7.5 mm. depth.
9 Bottles, 1 oz., with dropper pipette in screw cap, for test reagents.
3 Bottles, 2 oz., with dropper pipette in screw cap.
1 Bottle, glass dropping stopper, 1 oz. (for nitrate reagent).

Preparation of Solutions and Reagents for Routine Testing

(All chemicals should be of reliable C. P.
or A. R. grade, or of special type as noted)

Universal soil extracting solution: Add 100 gms. of sodium acetate ($NaC_2H_3O_2.3H_2O$) to 500 ml. of distilled water. After this is dissolved, add 30 ml. of glacial acetic acid and make up to 1 liter.

Nitrate nitrogen reagent: Dissolve 0.05 gm. of diphenylamine in 25 ml. of concentrated sulfuric acid, at a temperature not to exceed 24° C. The resulting solution should have no trace of bluish color, and should give a colorless "spot" when 4 drops are added to 1 drop of distilled water. This test should be made frequently since continued exposure to light and accidental contamination may require the preparation of a fresh reagent. The solution is very corrosive, and should not be allowed to come into contact with rubber. Care should also be taken to prevent injury to hands or clothing.

Ammonia nitrogen reagent: ("Nessler's reagent"): Dissolve 5 gms. of potassium iodide in 15 ml. of distilled water. Add a saturated solution of mercuric chloride until a slight precipitation occurs. Add 40 ml. of a 50 percent solution of potassium hydroxide. Dilute to 100 ml., allow to settle for one week, decant and keep in a brown glass bottle. Two drops of this reagent, added to 4 drops of the "Universal" leaching solution, should give a practically colorless spot. Nessler's reagent prepared according to other reliable laboratory formulae may also be employed.

Phosphorus reagent "A": Dissolve 12.5 gms. of sodium molybdate, by gentle heating, in 100 ml. of distilled water. Mix 50 ml. of acetic acid and 350 ml. of distilled water in a 600-ml. beaker. Add the above solution of sodium molybdate slowly with constant stirring. Store in a brown glass bottle.

Reagent "A" should not show more than a trace of sediment in the bottle in which it is stored. If the molybdate has a definite tendency to precipitate, the reagent is unreliable. This reagent, when carefully prepared, should be stable for six months or more; but unless the directions are carefully followed, it may deteriorate in a much shorter time.

Phosphorus reagent "B": *This should be freshly prepared on the day of use* as follows: Place 25 ml. of "Universal" extracting solution in a one-ounce dropper bottle. Add .005 to .01 gm. of stannous oxalate (an amount about the size of a match head, conveniently transferred by means of the flattened tip of a thin glass rod) and shake thoroughly.

Potassium reagent "A": Dissolve 5 gms. of $Co(NO_3)_2$ and 30 gms. of $NaNO_2$ in 50 ml. of distilled water acidfied with 2.5 ml. of glacial acetic acid. Make up to 100 ml. with distilled water. Let stand 24 hours and filter.

Potassium reagent "B": Iso-propyl alcohol, 90 ml., mixed with formaldehyde, neutral, 10 ml. (Store in a bottle with a tightly fitting screw cap).

Calcium reagent: Mix 10 gms. of sodium oxalate with 100 ml. of distilled water. Let stand for 24 hours, and decant clear supernatant solution to the reagent bottle for use as required.

Magnesium reagent "A-1": Dissolve .01 gm. of para-nitrobenzene-azo-resorcinol (Eastman Kodak Company) in 2 ml. of 1 percent NaOH. Dilute to 200 ml.

Magnesium reagent "A-2": Dissolve 0.10 gm. of Titan yellow (Eastman Kodak Company) in a mixture of 50 ml. of methyl alcohol and 50 ml. of distilled water. This should be freshly prepared every three or four months.

Magnesium reagent "B": Dissolve 15 gms. of sodium hydroxide in 100 ml. of distilled water. This is also used as Manganese reagent "B".

Aluminum reagent: Place 0.05 gm. of hematein (Eastman Kodak Company) in a 30-ml. beaker. Add 5 ml. of ethyl alcohol (95 percent.) Triturate with a rubber tipped stirring rod and decant clear solution to the storage bottle. Triturate with successive 5 ml. portions of alcohol and decant, until all of hematein is dissolved. Make up to a volume of 100 ml., with the ethyl alcohol. (This should be freshly prepared every two months, under ordinary conditions of storage).

Aluminum stain remover: Mix 25 ml. of concentrated hydrochloric acid and 25 ml. of distilled water. (Same as Iron reagent "A").

Manganese reagent "A": Dissolve 0.1 gm. of benzidine in 20 ml. of glacial acetic acid. Dilute to 200 ml. and filter.

Manganese reagent "B": See Magnesium reagent "B".

Preparation of Reagents and Extracting Solutions for Special Tests

Iron reagent "A": Dilute hydrochloric acid of ordinary C. P. concentration (approximately 38 percent HCl) with an equal volume of distilled water.

Iron (ferric and ferrous) reagent "B": Dissolve 10 gms. of potassium ferrocyanide and 0.1 gm. of potassium ferricyanide in 100 ml. of distilled water.

Ferric iron reagent "B": Dissolve 15 gms. of potassium sulphocyanate in 100 ml. of distilled water.

Ferrous iron reagent "B": Dissolve 0.2 gm. of potassium ferricyanide in 100 ml. of distilled water.

Sulfate sulfur reagent: Dissolve 5 gms. of barium chloride in 100 ml. of distilled water.

Nitrite nitrogen reagent: Dissolve 1 gm. of sulphanilic acid, by gentle heating, in 100 ml. of a saturated solution of ammonium chloride. Add 1.5 gms. of phenol and mix thoroughly.

Special sodium extracting solution: Add 2 ml. of copper sulfate solution (10 percent) to 100 ml. of distilled water.

Sodium reagent: Make up two separate lots as follows: (A) Uranyl acetate, 10 gms.; acetic acid (30 percent), 6 ml.; distilled water to 65 ml. Dissolve by heating. (B) Zinc acetate, 30 gms.; acetate acid (30 percent), 3 ml.; water to 65 ml. Dissolve by heating. Add (A) to (B) and continue heating until clear. Let stand several days and filter out the sediment.

Chloride reagent: Dissolve 2 gms. of silver nitrate in 100 ml. of distilled water. Store in an amber, glass-stoppered bottle.

Boron reagent "A": Dissolve 0.5 gm. turmeric powder in 100 ml. of ethyl alcohol (95 percent). Filter through a "double acid-washed" paper.

Boron reagent "B": Mix 70 ml. of orthophosphoric acid (85 percent) and 30 ml. of concentrated sulfuric acid. Let stand for a few days, and decant the clear liquid.

Zinc reagent "A": Dissolve .0807 g. of cobalt chloride in 100 ml. of 0.5 N hydrochloric acid solution.

Zinc reagent "B": Dissolve 8 gms. of mercuric chloride and 9 gms. of ammonium thiocynate in 100 ml. of distilled water. Let stand for three or four days and decant the clear solution.

Zinc reagent "C": Ethyl ether.

Copper reagent: Dissolve 5 gms. of alphabenzoinoxime in 100 ml. of ethyl alcohol (95 percent).

Manganese reagent for supplemental test: A saturated solution of tetra-base (Eastman Kodak Company) in ethyl alcohol (95 percent.).

Mercury reagent: Dissolve 0.1 gm. of s-diphenylcarbazide in 100 ml. of ethyl alcohol (95 percent).

Lead reagent: Dissolve 0.05 gm. of dithizone in 100 ml. of carbon tetra-chloride. This should be freshly prepared, since most glass containers contaminate the reagent after a few days of contact.

Arsenic, material required for the test: Concentrated sulfuric acid, granular zinc AR (low arsenic content), silver nitrate solution (see Chloride reagent).

The Soil Extraction

The procedure that has been most extensively used with success on the sandy and loam soils of Connecticut involves direct extraction of the soil by percolation of the soil mass as placed in the folded filter paper cone. This technique works best on soils that are readily moistened throughout upon the addition of the first two or three ml. of the extracting solution, so that the remainder of the liquid percolates readily through the entire soil mass. Other investigators using the Universal soil extracting solution or similar types of extractants have adopted other procedures of extraction. While less simple and rapid than the author's original technique, they may be used to advantage on soils that are less readily saturated with the extractant, or that are of more impervious texture. Hence, alternate procedures of extraction are included.

Simple percolation extraction: Fit a folded filter paper of 9 cm. diameter (of American-made C.S. and S, 597, Munktell No. 0 or similar grade) into the funnel of the soil filtering tube or the funnel in position above the tube or flask to be used in the collection of the extract. Place a level teaspoonful of the soil sample inside the filter cone, and press down gently with the back of the spoon. Measure out a 10 ml. portion of the Universal soil extracting sloution, and pour slowly over the soil mass in the filter. If the soil does not readily absorb the liquid, the extraction should be repeated with the soil moistened slightly with distilled water before being measured into the funnel. Permit the filtration to proceed to completion, or until there is no liquid on the soil surface. In removing the filter cone of soil, squeeze it gently to extract any remaining liquid which may have collected at its tip. Remove the funnel and insert a clean eyedropper pipette into the filtrate vessel. Pump the liquid up and down the pipette two or three times to insure thorough mixing of the soil extract. Each lot of extract should be supplied with an individual pipette for transferring portions for the various tests.

Alternate extraction I: Place a teaspoonful of soil, gently packed and leveled, into a 50-ml. beaker. Add 10 ml. of the Universal soil extracting solution. Stir vigorously for one minute and filter through a paper of quality indicated above into a 20 by 75-mm. glass vial or other suitable container. Remove the funnel, and insert a clean eyedropper pipette into the filtrate vessel. Proceed as directed above.

Goss and Owens (23) recommend placing the soil and extracting solution in a 50-ml. Erlenmeyer flask and shaking with an automatic shaking machine for 15 minutes before filtration. Results by such a procedure are somewhat higher, for some constituents, than by the shorter time of extraction. However, data on check soils by various methods do not show any consistent improvement in correlation for the more exhaustive extraction.

Alternate extraction II: Place a rubber policeman over the end of the stem of a 50-mm. filter funnel provided with an 18-mm. disc of fritted glass (porosity-1). Add 10 ml. of the extracting solution and a level teaspoonful of the soil sample. After 15 minutes, remove the policeman, permitting the extract to drain into the collecting flask or tube. This general procedure is used by Thomas and Williams (47) and by Miles (31). Results have not been studied in detail in comparison with the simple percolation extraction, but are believed to be similar to those obtained by the Goss and Owens modification.

It is likely that no one method of extraction will be uniformly applicable to all types of soil. It is suggested that each of the procedures be studied on numerous soils representative of the locality involved, before selecting the one that appears to be most desirable.

Lighting Conditions in Conducting the Tests

It is possible to make reasonably close comparisons of color and turbidity reactions developed in the various quick tests under good natural light. A north or northeast window is preferable, since the reflections obtained in direct sunlight make matchings difficult. Very dark cloudy days and late afternoons in the winter season are an objectionable feature of natural lighting; hence, if possible, artificial illumination by a good lamp of the "daylight" type, preferably the recently devised fluorescent tube, with suitable screen to throw the light down and behind the table upon which the testing operations are in progress, is desirable. The value of attention to lighting and other details in soil testing techniques has been discussed by Constable and Miles (10).

Tests Most Commonly Used in Routine Testing

Nitrate nitrogen test[1]: Transfer 1 drop of soil extract to the spot plate. Add 4 drops of the reagent; let stand for two minutes; stir with a glass rod and compare the intensity of the resultant blue color with the color chart. The true color is slightly more blue than shown.

Stirring immediately after adding the reagent is not recommended, since the blue color develops most rapidly in the film of contact between the reagent and the extract. Somewhat deeper colors result from the prolonged standing in excess of two minutes, but for convenience of operation, the charts are standardized on the basis of this time.

If a very deep blue color is obtained, corresponding to the top value of the chart, the test should be repeated on 1 drop of diluted extract, prepared in the ratio of 1 drop of extract to 4 drops of water or the extracting solution. Heavily fertilized soils often contain several times as much nitrate nitrogen as indicated by the chart, on the basis of the undiluted soil extract.

If the first drop of the reagent produces an immediate blue color, the presence of nitrogen as the nitrite is suggested, and a test for nitrite is desirable.

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[1] This is adapted from the method originally proposed by the author (34).

Ammonia nitrogen test[1]**:** Transfer 4 drops of the soil extract to the spot plate. Add 2 drops of the reagent. Let stand one minute; stir with glass rod and compare the resultant yellow to orange color with the color chart.

Phosphorus test[2]**:** Transfer 10 drops of the soil extract to the spot plate. Add 1 drop of reagent "A" and 2 drops of reagent "B" (the latter freshly prepared on the day of use). Stir, let stand for one minute and compare the intensity of blue color with the color chart.

If more than 1 drop of reagent "A" is added, the test is abnormally high. If more than 2 drops of reagent "B" are used, or if that reagent contains more than the designated amount of stannous oxalate, a "dirty" blue or greenish blue color results.

The test should be read in one minute since, with a longer period of standing, the soil extracting solution, when tested as a blank, develops a definite blue color. Also, the blue color tends to develop a hue not readily matched with the chart, upon standing for a longer time.

Occasional golf greens soils and other soils that have been treated with mercury compounds have been encountered that yield a grayish to black precipitate upon the addition of reagent "B". This is due to reduction to metallic mercury by the stannous compound in this reagent. In such a case, the phosphorus cannot be reliably measured.

Soils that have been treated with heavy amounts of arsenic compounds for insect grub or earthworm control may give abnormally high posphorus tests. However, moderate treatments and arsenical spray residues rarely affect the test, by the procedure described above.

Potassium test[3]**:** Transfer 10 drops of the soil extract to the test vial (10 mm. inside diameter). Add 1 drop of reagent "A" and 10 drops of reagent "B". Let stand one minute; shake the vial gently and let stand two minutes longer. Estimate the resulting amount of yellow precipitate by the following use of the "line" chart:

> Hold the vial vertically, directly over the lines on the chart, with the bottom of the vial 1 inch above them. Look down through the vial at the different groups of lines, until the set is found which can be **barely perceived.** The test is read which corresponds to this set of lines.

The printed "line" chart does not permit precise differentiation at the lowest tests. If but the faintest perceptible turbidity is to be observed, the estimate should be "very low", with a Relative Test Index of 1. If the liquid remains clear and limpid, the estimate should be "extra low", with a Relative Test Index of 0.5.

If the test is beyond the visibility of the deepest lines on the chart, a preliminary dilution of the extract with the extracting solution may be made. It is necessary to mix fully the diluted liquid before testing.

[1] This is adapted from the procedure originally proposed by the author (35).

[2] This is adapted from the color reaction test of Deniges (12).

[3] This is adapted from the method originally proposed by Bray (6).

Calcium test[1]: Transfer 10 drops of the soil extract to the test vial. Add 1 drop of the reagent, shake vigorously and let stand for five minutes. Compare the resultant white turbidity with the chart, using the following procedure:

> Hold the vial vertically over the black background to the left of the gray discs, with the bottom of the vial one inch above the chart. Look down through the vial, comparing it with the various discs on the chart.

Magnesium test[2]: Transfer 10 drops of the soil extract to the spot plate. Add 1 drop of reagent "A-2" and 3 drops of reagent "B". Stir, let stand one minute and compare the resultant light salmon to deep red color with the chart.

If a "high" or "very high" reading is found, it is desirable to repeat the test, using reagent "A-1", which is especially sensitive in this range, in place of reagent "A-2". The procedure is otherwise the same. A deep blue test is read as "very high", while with decreasing amounts of magnesium, lavender and pink colors are obtained. No separate chart is included for reagent "A-1". In the lower ranges of magnesium concentration, reagent "A-2" gives more readable tests.

The magnesium test is somewhat affected by aluminum in amounts sufficient to give high or very high tests. Under such conditions, the magnesium test is somewhat lower than should be represented by the amount actually extracted from the soil. Due allowance should be made for this factor in interpreting the tests.

Soils of high active calcium content give extracts that tend to coagulate the magnesium color, making test readings difficult and unreliable. This may be overcome in most cases by adding 4 drops of a 50 percent glycerin solution prior to adding Reagent "A". The liquid in the test cup should be stirred thoroughly with a glass rod before adding Reagent "B".

Aluminum test[3]: Transfer 2 drops of the soil extract to the spot plate. Add 2 drops of the Universal soil extracting solution and 1 drop of the reagent. Let stand one minute, and compare the resultant yellow, brownish yellow to lavender color with the chart. The true top color is slightly more blue than shown.

If a "dirty" blue-gray color results from this test, it is indicative of abnormal concentrations of active ion; hence a test for this constituent is desirable.

After completing the reading, add 1 drop of the aluminum stain remover (1:1 HCl) and shake the block gently before washing it. This prevents the formation of a stain on the porcelain which interferes with subsequent tests.

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[1] This is adapted from the procedure proposed by the author (35).

[2] This is adapted from the spot plate test of Feigl (18) in the employment of the "A-1" reagent, and from the method of Spurway (45) in the use of the "A-2" reagent.

[3] This is adapted from the use of logwood extract in the testing for aluminum by Colwell and Parker (9).

Manganese tests[1]: Transfer 10 drops of the soil extract to the spot plate. Add 2 drops of reagent "A", stir and add 1 drop of reagent "B". Stir and compare the resultant blue color with the chart as quickly as possible, since the intensity of color fades rapidly after a few seconds.

If more than 1 drop of reagent "B" is added, or if the tip of the pipette used in transferring that reagent is abnormally large, the test may fail, since too much alkalinity interferes with the test.

If the soil contains abnormal concentrations of nitrite nitrogen, a brownish yellow discoloration is to be noted in the routine manganese test.

If no perceptible blue color is detected, add 2 drops of reagent "C". Stir at once with a glass rod and let stand for two minutes. If not more than a faint blue color appears, the test is recorded as "negative", and the soil contains less than 2 pounds of manganese per acre. If there is a strong blue color, without a trace of green or yellow, a "trace" amount is read, representing approximately 2 pounds per acre. If the color is green, gradually changing to yellow, this is recognized as "trace plus", or approximately 3 pounds per acre. If any blue color was apparent in the previous stage of testing, a deep yellow to orange-yellow color develops almost at once.

The above additional procedure is especially useful in differentiating soils suspected of being manganese-deficient.

The following alternate procedure may also be used to advantage when little or no reaction is obtained from the above method: Transfer 10 drops of the soil extract to the spot plate. Add 1 drop of reagent "C" and 1 drop of the special supplemental reagent (Tetrabase solution). A deep blue color develops almost at once in soils usually rated as "very low" or better by the regular method. When the resultant color is only faintly blue, the test may be considered as "negative". With experience, an operator can readily distinguish differences between tests even with the traces of extractable manganese that usually typify manganese-deficient soils. A similar method has been used by Thomas. (48) It should also be noted that traces of the violet permanganate color can be observed upon the addition of reagent "C", alone, after two or three minutes, when the extract contains a considerable amount of manganese.

Special Chemical Tests

One or more of the following tests may be of definite diagnostic value, under conditions that seem to warrant them, or when the abnormal conditions of the soil are not evidently correlated with the routine tests.

Iron test (both ferric and ferrous)[1]: Transfer 10 drops of the extract to the spot plate. Add 3 drops of reagent "A" and 1 drop

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[1] This is adapted from the spot plate test of Feigl (16).

[2] This was introduced by the author (37) as a soil test.

of reagent "B". Stir, let stand two minutes. The resultant colors indicate amounts approximately as follows:

Color	Test	Relative Test Index
Blue	Very high	10
Blue green	High	8
Apple green	Medium high	6
Pale green	Medium	4
Greenish yellow	Low	2
Lemon yellow	Very low	1

In this and subsequent iron tests, care should be taken to prevent the soil extracting solution or soil extract from coming in contact with any implement or piece of apparatus containing metallic iron.

Ferric iron test: Transfer 10 drops of the soil extract to the spot plate. Add 3 drops of reagent "A" and 1 drop of reagent "B". Stir and let stand two minutes. The resultant colors represent amounts approximately as follows:

Color	Test	Relative Test Index
Deep brownish red	Very high	10
Medium brownish red	High	8
Pale brownish red	Medium high	6
Very pale brownish red	Medium	4
Slight reddish tint	Low	2
Very faint reddish tint	Very low	1

Ferrous iron test: Transfer 10 drops of the soil extract to the spot plate. Add 2 drops of reagent "A" and 1 drop of reagent "B". Stir and let stand two minutes. The resultant colors and corresponding tests are the same as indicated for the above general iron test (ferric and ferrous).

A suggested alternate test for ferrous iron employs a reagent prepared as follows: A 1 percent aqueous solution of alpha-alpha-dipyridyl, aciduated with 1 ml. of concentrated hydrochloric acid per 100 ml. Ten drops of the soil extract, treated with 2 drops of this reagent, give a deep red color when considerable ferrous iron is present, grading to no color when no ferrous iron is present. This is a somewhat more sensitive test than that described above.

Sulfate sulfur test: Transfer 10 drops of the soil extract to the test vial. Add 1 drop of the reagent. Shake vigorously and let stand for five minutes. The calcium chart is used in reading the results.

Since this test is not sensitive over the range of concentrations existing in most soils of humid regions, except as a result of heavy applications of sulfate materials, it is not conducted as a routine procedure.

Nitrite[1] nitrogen test: Transfer 10 drops of the soil extract to the spot plate. Add 1 drop of the nitrite reagent, 1 drop of hydrochloric acid (1:1) and 4 drops of magnesium reagent "B" (15 percent NaOH). Stir and let stand one minute. The resultant colors may be rated from the following:

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[1] This is adapted from the test as employed by Spurway (45)

Color	Test	Relative Test Index
Yellowish orange	Very high	10
Orange yellow	High	7
Lemon yellow	Medium	4
Pale yellow	Low	2
Trace of yellowish tint	Very low	1

Soils very rarely show readable nitrite tests under normal field conditions.

Sodium test[1]**:** Since the Universal soil extracting solution contains sodium, the soil must be extracted with special sodium extracting solution. The procedure of extraction is not otherwise different.

Transfer 5 drops of the extract, thus obtained, to a test vial. Add 20 drops (1 ml.) of the reagent. Shake vigorously at one minute intervals for 10 minutes and compare, using the potassium chart.

Soils in humid regions, except those receiving overflow water from oceanic tides, rarely show readable tests by this procedure. This test is especially applicable to alkaline conditions existing in arid soils.

Chloride test[2]**:** Since the Universal soil extracting solution gives a precipitate of silver acetate when tested with the chloride reagent, the soil must be extracted with the special chloride extracting solution, or by distilled water, if clear extracts can be obtained thus. The procedure of extraction is the same in other respects.

Transfer 10 drops of the soil extract, so obtained, to the test vial. Add 1 drop of the reagent. Shake vigorously, and compare. using the calcium chart.

This test is valuable on saline soils, or when contamination from sea water or sea spray is suspected. Normal soils of humid regions rarely give readable tests, except when recently receiving liberal amounts of fertilizers containing chlorides.

Carbonate test: A soil containing carbonates in appreciable amounts is readily identified by the development of effervescence on the soil surface when the Universal soil extracting solution is filtered through it. This usually results in the development of a convex soil surface at the end of the extraction. No quantitative measurement is attempted.

Soils high in carbonates also give extracts which show white precipitates on the addition of an alkaline reagent (Ammonia reagent or magnesium reagent "B"). Normally this precepitate does not interfere with the color reactions and is due to the formation of calcium hydroxide in excess of its solubility.

Boron test[3]**:** Place 1 level tablespoonful of soil in a 30 ml. beaker Add the Universal soil extracting solution slowly, a few drops at a

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[1] This is adapted from the test as employed by Spurway (45).

[2] This is adapted from the test as employed by Spurway (45).

[3] This is adapted from the test proposed by the author (38). Helpful suggestions have been provided by T. R. Swanback of this Station.

time, stirring the soil mass with a glass rod, until the soil is thoroughly wetted. Add an additional 5 ml. quantity of the soil extracting solution. Stir for one minute. Filter. Transfer 5 drops of the extract to a spot plate depression. Add 2 drops of pure glycerin (AR). Add 1 drop of reagent "A" and 6 drops of reagent "B". Stir thoroughly and let stand for 15 minutes. A clear lemon yellow is negative, representing an amount of boron below the limits of sensitivity of the test. Boron is indicated by increasing depths of a reddish color. A golden yellow, very slightly tinged with red, appears at approximately 2 p.p.m. in the extract. At 4 p.p.m., a pale peach color appears. At 10 p.p.m., a deep peach color develops. At 20 p.p.m., a salmon red is in evidence. At 50 p.p.m., or higher concentrations, a full red color is obtained. The color deepens quite materially during the first few minutes.

Boron tests should be conducted at the same time as "blank" tests on the Universal soil extracting solution itself. The number of drops of reagent "B" may need to be adjusted. It should be 1 drop less than the amount required to produce a barely perceptible reddish tinge to the blank test. (A red color can be developed in the absence of boron, by adding an excess of the acid reagent "B".

Boron tests should be calibrated carefully on the basis of standards prepared from boric acid dissolved in the Universal soil extracting solution.

It has been noted that with soils giving high iron or aluminum tests the boron test color may be erroneously in evidence, while high amounts of nitrates tend to diminish the sensitivity of the test. Hence, if possible, the boron test should be confirmed by employing a laboratory procedure, such as the hot water extract method of Berger and Truog (3). It is doubtful if the limits of boron deficiency for most crops can be estimated by the quick test procedure.

Zinc test[1]: Prepare the soil extract in the same manner as for the boron test. Transfer 10 drops of the extract to a test vial. Add 4 drops of reagent "A" and 10 drops of reagent "B". Shake thoroughly and let stand for two minutes. Add 20 drops of reagent "C". Shake gently and let stand for 10 minutes. The appearance of a blue color at the film of contact between the ether and the aqueous solution is evidence of zinc. A barely perceptible film of blue indicates approximately 10 parts per million in the extract. Above about 25 p.p.m., a blue precipitate begins to accumulate in the bottom of the vial. The test should be compared with those obtained from standard amounts of zinc as zinc acetate, dissolved in the Universal soil extracting solution. It has not yet been possible to calibrate the above amounts in the extract in terms of that which is active in the soil. However, the presence of considerable zinc, thus shown, is evidence of the accumulation of harmful concentrations, as occassionally found in the vicinity of industrial plants processing zinc ore or metal.

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[1] This is adapted from the method of Krumbholz and Sauchez (30).

Copper test[1]: Prepare the soil extract as for the boron test. Transfer 10 drops of the extract to the spot plate.. Add 2 drops of the reagent. Stir and let stand for five minutes. A barely perceptible trace of greenish yellow color is observed when approximately 2 p.p.m., of copper are present in the extract. The color deepens in greenish hue, with higher amounts, being quite definite at 5 p.p.m.. at 10 p.p.m., a good apple green color is developed. Readings of the test should be calibrated against standard amounts of copper, as copper sulfate, dissolved in the Universal soil extracting solution.

The copper test is especially useful in examining soils with considerable accumulations of spray residues.

Mercury test[2]: Prepare the soil extract as for the boron test. Transfer 10 drops of the extract to the spot plate. Add 2 drops of the reagent. Add 3 drops of sodium hydroxide solution (same as Magnesium reagent "B"). Stir and let stand for one minute. A pale salmon red, from the indicator itself, is a negative test. A deep salmon red is observed when approximately 5 p.p.m. are present in the extract. The color is a deep red at 10 p.p.m., violet red at 20 p.p.m., violet at 50 p.p.m., purple at 100 p.p.m. Readings of the test should be calibrated against standard amounts of mercuric chloride, dissolved in the Universal soil extracting solution.

The mercury test is occasionally useful in revealing mercury accumulations from fungicides containing this element. It confirms the indication of mercury in the phosphorus test, and is considerably more sensitive.

Lead test[3]: Prepare the soil extract as for the boron test. Transfer 5 drops of the extract to the test vial. Squeeze out 1 drop of the reagent upon the center of the liquid surface. The green colored spot thus formed should remain undisturbed. Observe during a two-minute period. If the color of the spot remains green, no measurable amount of lead is present in the extract. At approximately 10 p.p.m. (in the extract), an olive green hue develops in two minutes; at 20 p.p.m., the resultant color is olive brown; at 40 p.p.m.,— reddish brown; at 60 p.p.m. — brick red within one minute; at 100 p.p.m. — brick red in one half minute.

The lead test is useful in identifying soils treated with lead compounds in insect control, or soils contaminated with lead compounds as residues from sprayed crops. It should be noted that mercury compounds give a golden yellow color, and zinc salts give a cherry red color, with the reagent used in the lead test.

Arsenic test[4]: Prepare the soil extract as for the boron test. Place a few grains of granular zinc in the bottom of a test vial. Add 5 drops of concentrated sulfuric acid. Add 10 drops of the soil extract. Place a disc of filter paper, approximately 15 mm. in diameter,

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[1] This is adapted from the method proposed by Hosking (29).

[2] This is adapted from the method of Feigl and Neuber (17).

[3] This is adapted from the method of Fischer (21).

[4] This is adapted from the Feigl (19) modification of the original Gutzeit test.

over the top of the test vial. Moisten the filter paper with 1 drop of silver nitrate solution (Chloride reagent). Shake the vial gently several times, until gas bubbles are freely liberated. Let stand for two minutes. Examine the bottom side of the test paper disc. A faint yellowish or silvery sheen, with no perceptible darkening, is a negative test, the slight coloration resulting from other constituents that may be present. With increasing amounts of arsenic, the test paper shows darker spots. The test is sensitive to approximately 10 parts per million in the extract.

The arsenic test is useful in studying arsenic accumulations and residues from insect control treatments, sprays and dusts.

Special Precautions

All glassware, spot plates, stirring rods, etc., should be washed with clean tap water and rinsed with distilled water immediately after being used. The spot plates require occasional cleaning with a sulfuric acid-dichromate cleaning solution, to remove stains.

The eyedropper pipettes may be flushed by vigorously pumping water from a beaker in and out of them by intermittent pressure on their bulbs. Any adhering precipitates should be carefully brushed loose from the bottoms of the test vials before final rinsing.

Reagent bottles should be kept clean, and encrustations should not be permitted to accumulate around their caps.

Any reagent that fails to give a satisfactory blank test with the soil extracting solution, or that fails to give high tests on "check" soils consistently giving high results on previous trials for a given constituent, should be rejected and replaced.

Transfer pipettes calibrated in .05 ml. subdivisions give greater accuracy of measurement. One drop is assumed to represent .05 ml., but there is a considerable discrepancy between many of the commercial eyedropper pipettes.

The Adaptation of the Tests to Plant Tissue Testing

During the past few years, numerous investigators have found it desirable to supplement quick tests of soils with similar tests conducted on fresh plant tissue or plant tissue extracts. It has been frequently possible thus to verify a case of suspected crop deficiency or other nutrient abnormality. The visible symptoms produced by serious deficiency or excess of a given constituent are frequently recognized by the trained observer. Such symptoms are well illustrated in a recent joint publication of the American Society of Agronomy and the National Fertilizer Association (1). However, in the field, the plant may suffer from combinations of various symptoms that are not readily identifiable. Under such conditions chemical plant tissue tests are often of much value.

Methods for such testing have been outlined by Thornton (49), Carolus (8) and Hester (27). A suggested adaptation, employing the

Universal soil extracting solution and the various tests previously described, is as follows:

Obtain fresh plant material from the growing crop, both from normal and questionable plants. Select small lots of the leaf petioles or succulent portions of the stem in the part of the plant most affected by any observable abnormal symptoms. Using a clean sharp safety razor blade, cut the material into fine bits not more than 2 mm. in length or thickness. Place 0.5 gm. of the material in a 50 ml. Erlenmeyer flask and add 10 ml. of the Universal soil extracting solution and a pinch of decolorizing charcoal. Shake vigorously for five minutes, and filter. The extract may be tested for various constituents by the procedures described for the soil tests.[1] The extract may require dilution with the extracting solution in order to bring the tests to a distinguished scale. Such dilutions should be in definite ratios (e.g.: 2 drops diluted to 10 drops, or 1 drop diluted to 4 drops).

The charts may be used in a comparative sense. However, no definite ratings can be used for general application, since the magnitude of the tests obtained on different species and under different growing conditions may vary significantly. Interpretations should be based on comparisons between plants of the same species and age and grown under the same general environment.

Hester (27) has proposed the use of the Waring blender or similar equipment for the comminution of the plant tissue material. In this procedure, 5 gms. of the tissue and 100 ml. of the extracting solution, together with one-quarter teaspoonful of clarifying charcoal (Darco or similar grade), are placed in the machine for a period of three to five minutes, until thoroughly comminuted. After filtration, the tissue extract is tested as usual. The amounts of decolorizing charcoal required to give a colorless extract varies with the different types of plant material.

Quantitative Calibration of Test Charts

The charts and scales of reading given in the back section of this bulletin were initially based on an assumption that a given constituent is extracted by the percolation of the 10 ml. portion through the soil mass in a fairly definite relation to the total amount that would become active, or extractable, by a series of successive extractions repeated until all that can be thus removed is recovered. On this basis, the first approximates the following percentages of the total thus extractable:

> Nitrate nitrogen — 80 percent; ammonia nitrogen — 50 percent; phosphorus— 4 percent; potassium — 50 percent; calcium — 50 percent; magnesium — 50 percent; aluminum — 10 percent; manganese — 20 percent; iron — 20 percent; sulfur — 80 percent; nitrite nitrogen — 80 percent; Sodium — 60 percent; chlorides — 80 percent.

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[1] In the manganese test on plant tissue extract, use four drops of reagent "A".

In the above connection, it is of interest to note that practically all of the nitrate and similar water-soluble constituents are removed by four successive extractions. The exchangeable bases, such as potassium, calcium and magnesium, are obtained in six or seven portions. On the other hand, the phosphorus concentrations of the second extract is usually slightly higher than the first. Successive extractions diminish only slightly in phosphorus content, even up to the twentieth portion. Aluminum and iron diminish slowly in concentration for six or seven extractions, and thereafter remain practically constant, with definite amounts of these constituents proportional to the amount in the first extract.

In previous publications on the Universal soil testing system (Bulletins **372** and **392**) these relationships have been used to calculate the number of pounds per acre to plow depth that would be represented by the test. Such an expression of results provides a helpful concept in evaluating the magnitude of the test, but has been frequently misused, or applied too literally, in the interpretation of results by some soil testing laboratories using these methods. Hence it has been decided to substitute the use of a Relative Test Index scale developed in the course of the correlation of results of the A.S.A. soil testing study referred to on a preceding page. This rating index scales up to 10 for the normal range of tests ordinarily encountered. The Index Number provides a helpful basis for comparing the quantitative magnitude of the test, and simplifies comparisons between tests.

Composite solution standards for the calibration of the charts: The color and turbidity charts given in this bulletin are the results of the best efforts of the engraver and printer. However, it is very difficult to obtain reproductions by the photo-engraving process. It is desirable to check them with solutions containing various concentrations representing the ranges of sensitivity of the tests. The following scheme employs a series of single stock solutions for each of the constituents in the routine tests. These are combined in a series of three mixed stock solutions that may be kept ready for reference at any time. The mixed stock solutions are combined and diluted in varying proportions in order to furnish convenient quantities for immediate comparisons. (Calculations from the exact concentrations employed, through the successive mixtures and dilutions, should not be used in an exact quantitative sense when such mixed standard is employed.)

1. Prepare separate solutions for each constituent, dissolving quantities of the C.P. chemical shown in the following table in *100 ml.* of the *Universal soil extracting solution:*

Constituent	Chemical	Gms. per 100 ml.	Concentration of Constituent p.p.m.
Nitrate Nitrogen	$NaNO_3$	.182	300
Ammonia Nitrogen	$(NH_4)_2SO_4$	.473	1,000
Phosphorus	$NaH_2PO_4.H_2O$	.036	80
Potassium	KCl	.191	1,000
Calcium	$Ca(C_2H_3O_2)_2.H_2O$	8.800	15,000
Magnesium	$Mg(C_2H_3O_2)_2.4H_2O$	.442	500
Aluminum	$AlCl_3.6H_2O$	.335	500
Manganese	$MnSO_4.4H_2O$	.162	400

2. Prepare three mixed stock solutions from the above separate solutions.

Mixed Stock Solution "A"
10 ml. of NO_3N (300 p.p.m.)
" " NH_4N (1000 ")
" " P (80 ")
10 " " Mg (500 ")
10 " " Universal soil extracting solution

Mixed Stock Solution "B"
10 ml. of K (1,000 p.p.m.)
10 " " Ca (15,000 ")
30 " " Universal soil extracting solution

Mixed Stock Solution "C"
10 ml. of Al (1,000 p.p.m.)
10 " " Mn (400 ")
30 " " Universal Soil extracting solution

The above may conveniently be kept available for ready use in 2-ounce dropper bottles.

3. For chart calibration, set up a series of 6 one-half ounce glass vials, numbered to correspond to Rating Index Number. A 10 ml. mark should be provided on each vial.

The amounts of the three mixed stock solutions to be added to each vial are as follows, in drops:

Relative Test Index:	1	2	4	6	8	10
Mixed Stock Solution "A"	1	3	6	12	18	30
" " " "B"	8	14	20	24	28	32
" " " "C"	1	3	6	12	18	30

Make up the contents of each vial to the 10 ml. mark with Universal soil extracting solution. Mix thoroughly. Test for each constituent as usual, except for Al, when *4 drops*, undiluted, should be tested. These standards are not suitable for the Mg-A-1 reagent procedure. When this reagent is used, omit mixed stock solution "C" in preparing the standards. This reagent is unreliable in the presence of significant concentrations of Al, and to some extent, in the presence of Mn.

The special tests may be calibrated with appropriate solution standards prepared from pure salts dissolved in the extracting solution and diluted to their proper range of sensitivity.

Application of Tests to Drainage Water from Soils, Irrigation Waters, Etc.

It is frequently desirable to obtain a rough picture of the relative amounts of various soluble chemical constituents in the drainage water from soils, water used for irrigation purposes, or from springs, wells and streams. The tests used for soil extracts can be applied for this purpose, although a few adjustments are required to compensate for the poor buffer action of such dilute solutions. The modifications are indicated below for the various routine and special tests that are thus affected:

Ammonia nitrogen: Use only 1 drop of the test reagent.

Phosphorus: Use only 5 drops of the water, adding 5 drops of the Universal soil extracting solution. Use only 1 drop of reagent "B".

Calcium: Add 2 drops of the Universal soil extracting solution to 10 drops of the water and mix before adding the test reagent.

Magnesium: Add 5 drops of the Universal soil extracting solution to 10 drops of the water and mix before adding the test reagents. Use only 2 drops of Reagent "B" (15 percent NaOH) in developing the test.

Aluminum: Use 4 drops of the water, add 1 drop of the Universal soil extracting solution and mix before adding the test reagent.

Manganese: Add 1 drop of 1:3 acetic (one part glacial acetic acid to 3 parts of distilled water) to 10 drops of the water and mix before adding the reagents.

Copper: Add 2 drops of the Universal soil testing solution to 10 drops of the water and mix before adding the reagent.

Carbonates: Place 2 ml. of the water in a test vial that has been very thoroughly rinsed with distilled water. Add 1 drop of phenolphthalein indicator (prepared by dissolving 0.5 gm. of phenolphthalein powder in 50 ml. of ethyl alcohol and diluting to 100 ml.). A pink to red color indicates the presence of carbonates. Add standard $KHSO_4$ solution (.034 gms. of potassium acid sulfate dissolved in 100 ml. of distilled water) drop by drop, until the pink color entirely disappears, after shaking. Each drop thus required is equivalent to 50 parts of carbonate (CO_3) per million, in the water tested.

In case it is desired also to estimate *bicarbonates* (HCO_3), add 1 drop of methyl orange indicator (0.1 gm. methyl orange in 50 ml. ethyl alcohol, diluted, to 100 ml. with distilled water), and continue the addition of $KHSO_4$ solution, drop by drop, until the yellow orange color changes to reddish orange. Each drop of $KHSO_4$ solution required, not including the amount required to decolorize the phenolphthalein, is equivalent to approximately 75 parts of bicarbonate (HCO_3) per million, in the water tested.

The other tests are conducted exactly as previously described in the section on soil extract testing.

Quantitative estimations in water tests: It is possible to make a fair estimate of the concentration of the various soluble constituents in water thus tested, within the range of sentivity of the test. Results are suitably expressed in terms of parts per million. The following table indicates the approximate amounts thus indicated, based on the use of the charts or described colors.

TABLE 1. APPROXIMATE QUANTITATIVE INDICATIONS IN WATER TESTS

Concentrations, in parts per million, at Relative Test Index shown on chart, or described

	1	2	4	6	8	10
Nitrate nitrogen	0.3	0.9	1.5	3	6	12
Ammonia Nitrogen	1	3	5	10	20	40
Phosphorus	0.2	0.5	0.8	1.5	3	6
Potassium	10	15	20	30	40	50
Calcium	100	150	200	300	400	500
Magnesium using A_2 reagent)	0.5	1	2	5	10	20
Aluminum	0.5	1	2	5	10	20
Manganese (A and B reagents only)	0.5	1	2	4	8	16
Iron	1.5	3	5	10	25	50
Sulfate sulfur	50	100	200	300	400	600
Nitrite nitrogen	0.5	1	2	4	6	10
Sodium	120	180	240	360	480	600
Chlorine	25	50	100	200	400	800

Boron	—	Sensitivity	range:	2 to 50	parts per million
Zinc	—	"	"	5 to 50	" " "
Copper	—	"	"	2 to 25	" "
Mercury	—	"	"	5 to 100	" "
Lead	—	"	"	10 to 100	" "
Arsenic	—	"	"	10 to 100	" "

Adaptation of Quick Tests to Saline or Alkali Soils

The method of soil extraction with an acetic acid-sodium acetate buffer solution, such as employed in the Universal soil testing system, is primarily adapted to soils of humid regions, containing relatively low amounts of water-soluble salts, and either acid or only slightly alkaline (below 8.2 pH) in reaction.

Saline or white alkali soils contain large amounts of water-soluble salts, such as the chlorides and sulfates of sodium, magnesium and calcium. When the salt concentration is fairly high (3,000 parts or more per million), a mixture of the soil with distilled water, for instance, 1 level teaspoonful per 10 ml. of distilled water, is sufficiently flocculated by the presence of the salts to yield a clear water extract upon filtration. However, if the salt concentration is low, or if the soil is deflocculated by the presence of alkali carbonate, a clear water extract is not thus obtained.

A suitable procedure for obtaining clear, colorless extracts of soils that may be reliably tested for the common alkali or saline constituents is as follows:

Place 1 teaspoonful of the soil in a 30 ml. beaker. Add 10 ml. of distilled water to which from 1 to 5 drops of a neutral 1 percent copper acetate solution have been added. (Heavy soils low in salts require more copper acetate to effect clarification. Use no more than is actually necessary to give a clear filtrate). Stir thoroughly for one minute, and filter through a paper of the quality used in the usual procedure.

The extract may be subjected to various tests following the techniques recommended for drainage waters, etc. The copper test, of course, cannot be included. The most useful tests are those for chlorides, sulfates, nitrates, sodium, calcium, magnesium and potassium. "Black alkali" soils yield extracts showing the presence of soluble carbonates by the phenolphthalein indicator. However, a pH test of the soil should be employed to confirm the presence of alkali. (Black alkali soils are indicated by pH tests above 8.5).

THE INTERPRETATION OF SOIL TESTS

SOIL test data should be considered with reference to the limiting effects on crop growth that may be expected from other factors, such as the following: poor aeration or restricted root system caused by undesirable soil structure or soil tilth, deficient drainage, unfavorable seasonal conditions, plant pests, plant diseases. Irrespective of the chemical fertility of the soil, the crop expectation is less than normal when one or more of these factors is in operation. It is impracticable to seek to attain the most desirable tests on soils otherwise restricted in productive capacity.

The economic productive level of the crop under consideration determines to a marked degree the extent to which one can afford to build up the fertility level of the soil. Fertilizers can be profitably applied in much larger amounts for crops capable of giving high net returns, per acre. This is conspicuously true of intensive vegetable crops, tobacco or potatoes, as contrasted with hay or pasture crops.

Soil test should be compared in the light of past practices with respect to fertilizers, manures and lime. Many obvious correlations may be observed. On the other hand, when the soil treatment has been so favorable as to justify an expectation of relatively high ratings for phosphorus, potassium and calcium, and a low test for aluminum, the explanation for less desirable tests should be sought, giving consideration to the fixing power of the soil and the degree of exhaustion of available constituents that could be accomplished by crop withdrawal.

Some tests, notably those for nitrate and ammonia nitrogen, depend upon temporary conditions, such as the activities of soil microorganisms, seasonal effects and amounts of leaching that have been in recent operation. A test may be given much weight, or entirely disregarded, depending upon whether or not the conditions have been such as to favor the accumulation of such conditions in the soil.

The interrelation of various quick tests and the pH test should be especially considered. Chemical soil fertility is best estimated from a study of the composite pattern thus presented.

No definite limits for favorable or unfavorable soil tests can be set for a given constituent, even for a particular crop, that will apply under all conditions. Sound judgment, thorough agronomic training and much experience in the applying of the results of soil tests on soils of known performance are all essential to the diagnostic interpretation of soil tests in terms of soil management practices. A laboratory technician who can follow simple chemical routines can be quickly trained to make tests described in this bulletin. The practical value of the tests is limited chiefly by the qualifications of the person who is responsible for translating the data into amounts and kinds of fertilizers, manures, lime and other soil amendments that are most likely to be effective in promoting profitable crop production.

The following details pertaining to soil test interpretation are based chiefly upon the author's experience in applying soil test results to many thousands of cases, chiefly on Connecticut soils, during the past 10 years, and to nearly 200 soils that have been exhaustively studied both by laboratory analyses and by crop responses to various treatments in greenhouse pot cultures. However, they may need to be considerably modified in interpreting soil test results on soils of other sections of the country, or for crops other than those commonly grown in this locality.

The interpretation of pH tests: As previously stated, pH tests do not directly indicate lime needs. The amount of lime required to change a soil from a given pH to a higher, less acid-indicating one, depends not only upon the change in pH to be effected, but also upon the base exchange capacity of the soil, chiefly as related to the organic matter and clay content of the soil within a given region. The soils of Connecticut may be roughly classified into four groups, as shown in Table 2.

Table 2. Soil Groups in Terms of Lime absorption as Related to pH Adjustment

Lime Absorption Group	Textural Class	Organic Mater Content Approximate Percent	Base Exchange Capacity*
I	Loamy sand	2 - 4	
	Sandy loam	1 - 3	4 - 6
II	Loamy sand	5 - 7	
	Sandy loam	4 - 6	7 - 10
	Fine sandy loam	2 - 4	
III	Sandy loam	7 - 10	
	Fine sandy loam	5 - 7	11 - 15
	Loam	3 - 5	
IV	Fine sandy loam	8 - 10	
	Loam	6 - 8	16 - 20
	Clay loam	3 - 6	

*In terms of milligram equivalents per 100 gms. of soil.

The degree of pH adjustment in the positive direction that is desirable depends upon the minimum pH at which the crop will give normal production on an otherwise favorable soil. Crops vary considerably in their range of adjustment to varying pH levels. However, for all practical purposes, four soil reaction preference groups are now reasonably well established. Crops representing these groups are shown in Table 3.

TABLE 3. SOIL REACTION PREFERENCE GROUPS

A	B	C	D
Alfalfa	Bluegrass	Beans	Arbutus†
Asparagus	Broccoli	Carrots	Azalea
Barley	Brussels Sprouts	Clover, alsike	Bent grass
Beets	Cabbage	Clover, white	Blueberries†
Celery	Cauliflower	Corn	Buckwheat
Lettuce	Clover, ladino	Eggplant*	Fescues
Onions	Clover, red	Fescue, red	Laurel†
Radishes	Cucumbers	Parsnips	Oats
Spinach	Muskmelons	Peppers	Potatoes
Sweet Clover	Peas	Pumpkins	Red top
	Rape	Soybeans	Rhododendron†
	Rhubarb	Strawberries	Rye
		Squash	Sweet potatoes
		Timothy	Vetch, hairy
		Tobacco*	Watermelons
		Tomatoes	
		Turnips	
		Wheat	

Group "A" crops are preferably grown on soils ranging from 6.2 to 7.6 pH. However, if the soils give negative manganese tests, and are above 6.4 pH, there are possibilities of manganese deficiency. With high calcium and low aluminum tests, most of these crops may be successfully grown at reactions as low as 5.8 pH.

Group "B" crops usually do well at reactions as low as 5.6 pH, unless the calcium test is low, or the aluminum test is high. They are not usually adversely affected by pH values up to 7.2, but it is preferable to maintain a slight degree of acidity (6.0 to 6.6 pH).

Group "C" crops do reasonably well down to as low as 5.0 pH, unless the calcium test is very low or the aluminum test is very high. The crops marked with an asterisk (*) need degrees of acidity ranging from 5.0 to 5.6 pH, because of disease trouble favored by higher reactions.

Group "D" crops are favored by a considerable degree of acidity, and may be grown successfully at reactions as low as 4.6 pH, if other factors are properly adjusted. Potatoes require reactions below 5.2 pH in order to protect them from scab. The plants marked with a dagger (†) are usually adversely affected by reactions above 5.4 pH.

Soils with high calcium tests, when the aluminum test is not high, should be interpolated on the basis of recommendations for the next lower crop group.

(Illustration: pH 5.6; very high calcium test; very low aluminum test. For crops in group II, lime as for crops in group III.)

Soils with high aluminum tests should be limed on the basis of the next lower pH interval, for the first two crop groups.

(Illustration: 5.6 pH; high aluminum test; low calcium test. Lime on basis of recommendations for 5.2 pH.)

Soils with low to extra low magnesium tests (relative test index below 3) should be limed with dolomitic (magnesian) lime if the pH test indicates that lime is needed. If the pH is sufficiently high so as not to require lime, magnesium should be used as magnesium sulfate or "double manure salts".

If the calcium is very low, and the magnesium test is very high, the liming should be in the form of a "high-calcic" material, preferably.

The following table (Table 4) is based on pH measurements made in spring or late fall. If tests are made in midsummer, it is desirable to add the following pH corrections, based on differences in soil, for the various groups, before applying the table of lime requirements at various pH levels:

Soil Group I — 0.5 pH
Soil Group II — 0.4 pH
Soil Group III — 0.3 pH
Soil Group IV — 0.2 pH

TABLE 4. LIMING RECOMMENDATIONS FOR VARIOUS CROP GROUPS IN RELATION TO SOIL AND pH

Amounts in tons of agricultural limestone, per acre
(Use three-fourths these amounts of hydrated lime)

	Crop Group A				Crop Group B			
	Soil Group				Soil Group			
	I	II	III	IV	I	II	III	IV
6.8	0	0	0	0	0	0	0	0
6.4	X	X	X	X	0	0	0	0
6.0	.5	.9	1.2	1.7	X	X	X	X
5.6	1.0	1.7	2.4	3.3	.5	.9	1.2	1.7
5.2	1.4	2.5	3.5	4.7	1.0	1.7	2.4	3.3
4.8	1.8	3.1	4.4	5.8	1.4	2.5	3.5	4.7
4.4	2.1	3.5	5.0	6.5	1.8	3.1	4.4	5.8

	Crop Group C				Crop Group D			
	Soil Group				Soil Group			
	I	II	III	IV	I	II	III	IV
6.4	*	*	*	*	Z	Z	Z	Z
6.0	0	0	0	0	Z	Z	Z	Z
5.6	0	0	0	0	*	*	*	*
5.2	.5	.9	1.2	1.7	0	0	0	0
4.8	1.0	1.7	2.4	3.3	.5	.9	1.2	1.7
4.4	1.4	2.5	3.5	4.7	1.0	1.7	2.4	3.3
4.0	1.8	3.1	4.4	5.8	1.4	2.5	3.5	4.7

Z For crops of this group, a more acid soil is desirable.
* Fertilizers with an acid residual effect should be used.
0 Neutral fertilizers preferable.
X Fertilizers with an alkaline residual effect should be used, or very light liming is optional.

The amounts shown in the previous tables are based on lime applications made to cultivated land, thoroughly worked into the soil in the preparation of the ground for cropping. When the lime is applied as a top-dressing, as on permanent sod, from one-half to one-third as much is all that should be used, since the soil can only be affected for two or three inches when lime is thus used.

Conditions Indicated by Various Quick Tests

Nitrogen tests (ammonia, nitrite and nitrate): Nitrogen exists in the soil largely in the form of partially decomposed organic residues containing proteins. Micro-organisms (bacteria and fungi) gradually transform this nitrogen into ammonia compounds. Organic nitrogenous fertilizer materials and leguminous crop residues are more readily attacked due to their high protein content. Urea and cyanamid are fertilizer materials that are rapidly hydrolyzed to produce ammonium compounds, while nitrogen in this form is directly supplied in fertilizer containing sulfate of ammonia, ammophos or ammoniated phosphates.

Nitrogen in ammonium compounds may be utilized as such by many plants, especially during their early growth, thus consuming the visible supply as indicated by the test. However, the chief reason for the failure of the ammonia test to reveal more than small amounts on normal field conditions is due to the rapid change to nitrites and nitrates by further bacterial activity. The pace of the change to nitrates is usually so rapid in proportion to that of the earlier stages of nitrogen transformation that only a few weeks after fertilizer applications supplying much ammonia, little or no ammonia nitrogen and no nitrite can be identified by tests. Except during a short period after such fertilizer treatment, a substantial ammonia test is an indication of unfavorable conditions for nitrification, such as high acidity, excessive or deficient moisture supply, or other abnormal factor.

Nitrite tests are rarely obtained, except as a temporary condition occasionally resulting from a very heavy nitrogenous fertilizer treatment that has not been well mixed into the soil, especially under poor aeration resulting from excess water. Nitrite tests in more than trace amounts should be considered as harmful. Instances of severe injury to plant growth have been noted on soils showing medium to high readings.

Irrespective of the diagnostic value of the ammonia tests, it is desirable to make it in order to identify inaccurately high apparent potassium tests on soils that contain unusual amounts of ammonia nitrogen.

Nitrate nitrogen, whether formed in the soil from nitrification of ammonia derived from organic residues and fertilizer materials, or directly supplied in the fertilizer (as, for example, nitrate of soda), is rapidly assimilated by the roots of living plants, and is readily lost from the soil by the percolating action of heavy rains. Hence high tests for nitrate nitrogen in field soils are to be expected only when the root system of the crop is not yet fully developed.

High tests indicate a large reserve of readily available nitrogen for the use of the crop as it begins to draw heavily upon the soil. Rapidly growing annual crops require a larger reserve during the early part of their life in the soil, since the gradual processes of nitrogen liberation are rarely sufficiently rapid to meet their requirements during the period of most active growth. Crops with perennial root systems, such as sod grasses, shrubs and trees, take up nitrogen through a much longer period of the year, and low nitrate tests do not necessarily indicate a lack of available nitrogen.

Low tests are to be expected at the end of the cropping period, during winter and early spring, and after a period of heavy rainfall. Under such conditions, when all other factors are favorable, the absence of nitrates may not indicate poor availability of soil nitrogen, but the crop is apt to respond to the addition of a readily available nitrogenous fertilizer.

Abnormally high nitrate nitrogen tests are occasionally encountered in greenhouse and other intensively fertilized soils, and are an indication of possible injury to the crop due to excessive concentration of the nitrate salts. Such a condition may be corrected by leaching the soils with large amounts of water.

Thus the nitrogen tests may either be given much significance or practically disregarded, depending upon whether or not conditions are favorable to the development of accumulations of these mobile constituents.

In order to give a reliable indication of the amount of readily available nitrogen in the soil, tests may be made on samples which have kept in "mellow-moist" condition, in a loosely covered vessel at a temperature of 60° F. or above, for several weeks. Low nitrate tests on such samples indicate real nitrogen deficiency in the soil. However, it is rarely practicable to do this on account of the delay thus involved.

Since other factors than the soil test are usually most important in assessing the amount of available nitrogen that is likely to be supplied by the soil during the active growing period of the crop, it is convenient to recognize one or more of the soil characteristics that are usually involved in rating a given soil with respect to the following *Nitrogen Availability Classes:*

I—*High*: Liberal manure applications (such as 15-25 tons of stable manure) within a few months preceding the crop; unusually favorable amount of soil organic matter, as indicated by dark color, provided that the soil is well drained and not strongly acid; high to very high nitrogen tests.

II—*Medium*: Light manure applications (8-14 tons of stable manure) within a few months preceding the crop; a large green manure or a heavy clover or alfalfa sod plowed under; medium to medium high organic matter, as indicated by medium dark color, under favorable drainage conditions; medium to medium high nitrogen test ratings.

III—*Low*: Average cultivated cropping conditions, or with grass sod plowed under; loamy soil texture, with fair organic matter content; low to very low nitrogen tests.

IV—*Very Low*: Cultivated crops on sandy soils of relatively low organic content; very low nitrogen tests.

The phosphorus test: Phosphorus occurs in unfertilized soils in slowly soluble mineral and organic combinations. It is a component of all mixed fertilizers, and is frequently applied alone as superphosphate or bone meal.

Under high levels of fertilization, in excess of 500 pounds per acre per year of fertilizers containing as much as 8 percent of "phosphoric acid", crops remove less phosphorus than is applied to the soil. This element is not leached downward. In soils of only moderate degrees of acidity, applied phosphates remain for long periods in fairly available form. On highly acid soils, containing much active aluminum and iron, difficultly soluble phosphate compounds are formed with these elements. At low rates of fertilization, the phosphorus supplied by the fertilizer results in little or no accumulation, and there may be a net loss when little manure or fertilizer is used. When such a soil receives little or no lime, low phosphorus availability is the most common condition.

The phosphorus test indicates the level of more readily available phosphorus in the soil, either native or as a residue from previous applications. There are marked differences in the abilities of various crops to thrive at the different degrees of phosphorus availibility shown by this test. Most market garden crops, potatoes, tobacco, and most legumes require applications of phosphatic fertilizers unless high tests are obtained. Many soils showing only medium tests grow good grass hay, corn, oats, and alsike clover with very little phosphorus fertilization, when otherwise in a fertile state. Low or very low tests indicate the necessity for proportionally high amounts of "phosphoric acid" in the fertilizer, depending upon the crop grown.

The active phosphorus content of the soil is a fairly stable property, except as affected by recent fertilizer application. Soils which have received applications of arsenical materials may give high tests, regardless of their phosphorus content. Hence results in such cases are subject to question.

At a given level of phosphorus availability, higher pH values (5.6 or above) tend to increase the test actually obtained. On the other hand, at greater degrees of acidity (below 5.0 pH), considerable amounts of slowly available aluminum and iron phosphates may be present in soils giving low tests. Reasonable allowance should be made for this factor, especially on soils known to have received considerable amounts of phosphorus in fertilizer applications during previous years.

The following conditions are usually to be considered in association with one another in determining the *Phosphorus Availability Classes:*

I—*High:* Liberal applications of complete fertilizers for several years, especially on a sandy soil; a slight degree of acidity; a low aluminum test; a high to very high phosphorus test.

II—*Medium:* Moderate applications of complete fertilizers for several years: light loam or sandy loam texture; moderate to slight acidity; a medium aluminum test; a medium or medium high phosphorus test.

III—*Low*: Light, infrequent fertilizer applications; a strong degree of acidity; a medium to high aluminum test; a low or medium low phosphorus test.

IV—*Very Low*: No fertilizers on previous crops; a loam, silt loam or clay loam soil; a very strong degree of acidity; a high or very high aluminum test; a very low phosphorus test.

The potassium test: Potassium occurs in soils in large amounts in the form of difficultly soluble rock minerals. Their gradual decomposition liberates small quantities of potassium which are loosely combined with colloidal material (clay and humus) capable of being displaced into the soil solution by base exchange reactions. Potassium is also added to the soil in fertilizers containing potash, or as manures or crop residues, and largely goes over into the exchangeable form. Some potassium is removed from the soil by leaching, especially when under cultivation and liberally fertilized.

The active potassium of the soil, best capable of nourishing the crop, is that which exists in exchangeable form, or in true solution. Quick tests indicate such supplies of this constituent.

Active potassium may be removed from the soil more rapidly than replenished by natural process. Thus tests may be lower at the end of the growing season of a crop with high potash requirements, than after the soil has been fallow or supporting little vegetation for several months. Hence most reliable tests are obtained in the spring, prior to fertilization.

Soils treated with liberal amounts of potassium fertilizers in recent years may contain some residues of moderately available potassium that are not recoverable by the methods of extraction described in this bulletin. This is due to the fixation of applied potassium in the non-exchangeable forms, from which the element may be more easily taken up by the crop than from the potassium existing in native soil minerals. Reasonable allowance for this factor should be made under such conditions.

The following conditions are usually to be considered in association with one another in determining the *Potassium Availability Classes:*

I—*High*: Heavy applications of complete fertilizers, supplying from 120 to 200 pounds of potash per acre, annually, or heavy treatment with manure of good quality; a loamy soil texture; calcium or magnesium tests not unusually high in relation to the potassium test; a high to very high potassium test.

II—*Medium*: Moderate applications of complete fertilizers, supplying from 40 to 100 pounds of potash per acre during recent years; fair applications of manure of good quality; intensive cropping; a medium heavy soil texture; a medium to medium high potassium test.

III—*Low*: Under intensive cropping, irrespective of past fertilizer treatment; under average cropping, with little or no fertilizer or manure, or with manure of poor quality (badly leached); a fairly low potassium test.

IV—*Very Low*: No fertilizer or manure; very sandy soil texture; a very low or extra low potassium test.

The calcium test: Calcium in soils occurs in the form of undecomposed carbonates (in calcareous soils), rock minerals, as exchangeable calcium (absorbed by the soil colloids) and as soluble calcium salts. Acid soils contain no carbonates and are depleted in exchangeable calcium. However, many soils which show a considerable degree of acidity by pH tests may have a fair amount of exchangeable calcium. This is especially true of soils high in organic matter or active mineral colloids. In many cases the calcium test is a better indication of lime needs than is the pH test.

Soils with high and very high calcium tests contain adequate amounts of calcium for all crops. Usually they do not respond to liming, unless a high active aluminum concentration is indicated. Medium calcium tests on soils near the neutral point may be expected on light sandy soils, but on acid soils a need for lime is revealed for growing alfalfa, sweet clover and lime-loving vegetable crops. A low calcium test on soils with a high aluminum test is a certain indication of lime requirement for all except the most acid-tolerant plants, such as blueberries, strawberries, or ericaceous shrubs. When a very low test results, lime should be used in liberal amounts for most crops, unless only moderate applications may be made with safety on account of disease factors.

Certain disease-producing soil organisms seem to be closely related to the available calcium in the soil, in relation to the other bases, especially potassium and magnesium. Thus club root is made less severe by increasing the calcium supply. Physiological root disturbances, such as the brown root rot of tobacco, are frequently engendered by calcium deficiency. On the other hand, the black root rot of tobacco and the scab organism on potatoes become more troublesome on soils with higher relative amounts of calcium.

It must be borne in mind that, unless all other tests are satisfactory, heavy liming may produce an abnormal soil balance. Thus liming has frequently proven injurious on many sandy soils of the southern United States which are deficient in other elements, such as magnesium, manganese, potassium or iron. A deficiency of boron in the soil is also accentuated by liming treatment.

The magnesium test: Magnesium occurs in soils in the following forms: Dolomitic carbonates; unweathered minerals; exchangeable magnesium, absorbed by the soil colloids; soluble magnesium salts.

High and very high tests for magnesium are developed from calcareous soils derived from dolomitic limestones, and from moderately acid soils resulting from the weathering of rocks high in ferro-magnesian minerals. Medium tests are more common on soils of moderate acidity, on calcareous soils from high calcic limestones, or on soils which have been moderately limed with material of dolomitic origin. Low tests are common on acid soils. Some strongly acid soils give very low or negative tests. This is particularly true of sandy soils. In such cases magnesium should be applied. The cheapest form is in dolomitic lime or limestones. On soils giving high calcium and very low magnesium tests, or pH values as high as desired for the crop, magnesium sulfate or other magnesium compounds commercially reclaimed from sea water may be used in order to supply magnesium without sweetening the soil. Commercial fertilizers which are thus formulated are now on the market.

The aluminum test: Aluminum occurs in large amounts in all soils, in the form of undecomposed minerals and in the inorganic colloidal material. In neutral, slightly acid or slightly alkaline soils, the element is in inert combinations that have no direct effect upon plant growth. At greater degrees of acidity, aluminum becomes active, capable of combining as soluble salts and thus exerting a toxic effect upon the growth of many plants, especially those which are benefited by liming when grown on acid soils. A high or very high test is a certain index of an undesirably acid soil, upon which acid-sensitive crops are almost certain to fail. A medium test is not serious, especially with grasses, corn, oats, potatoes, and tobacco. A low or negative test is desirable, except for distinctly acid-tolerant plants.

The manganese test: Manganese occurs in small amounts in all soils, chiefly in relatively insoluble combinations. In some calcareous soils and acid soils that have been heavily limed, practically no manganese is present in active forms, and some crops are unable to obtain even the small amounts necessary to meet their requirements. Poor growth and a yellow, chlorotic condition result.

On the other hand, strongly acid soils may contain injurious concentrations of active manganese compounds. Under such conditions liming is a corrective measure.

Manganese is changed by oxidation to less active forms, or may be leached from the soil. Hence tests are of most significance when made just prior to planting or during crop growth. A negative test at such time indicates the desirability of applying manganese. Twenty-five pounds of commercial manganese sulfate per acre are usually adequate to correct any possible deficiency. It is doubtful if manganese is needed if any positive test whatsoever is developed. Medium or moderately low tests are of little significance, except as indicating no manganese deficiency. High or very high tests are undesirable on all acid soils, and indicate a need for lime. The significance of high tests on soils which are neutral or alkaline has not yet been thoroughly studied. However, it is not likely that the crop will develop manganese toxicity except at the more acid soil reactions, even though the test is high.

The iron test: Iron is an abundant constituent of all soils, existing in the form of iron oxides and many complex mineral combinations. Normally only very small amounts of iron are in active form in the ferric state of oxidation. Under conditions of high acidity, larger amounts are to be found, and under poor drainage conditions, especially in the presence of organic matter, active ferrous iron compounds are developed. Soluble ferrous salts are harmful to plant growth, and contribute to the infertility of poorly aerated soils.

The presence of very low, yet definite amounts of active iron, as revealed by the test, is desirable for all crops. Higher amounts, on well drained soils, may not be injurious to crops capable of growing under strongly acid conditions. Abnormally high iron tests on poorly drained soils indicate an unfavorable condition of soil aeration.

Negative iron tests may occasionally result on heavily limed soils of excessive sandiness. In such cases, a chlorotic condition of the leaves may develop, which is controlled by spraying the plants with iron salts. No case of this sort has been encountered in this State.

Indication of other tests: Occasionally soils which give poor crops contain unusual or harmful concentrations of other chemical constituents. The presence of sea water or white alkali salts is indicated by chloride, sodium and sulfate tests. Soluble carbonates and high sodium tests indicate black alkali accumulations. Zinc, lead, copper, mercury and arsenic tests suggest the development of injurious amounts of these elements as a result of soil contamination by industrial plants, or as residues from soil treatments to control plant diseases or insects. The boron test may be applied when crops are suspected of boron deficiency, and if a positive test is not obtained, a more accurate laboratory test for boron should be applied.

ESTIMATING FERTILIZER NEEDS FROM NUTRIENT AVAILABILITY RATINGS

IN preceding pages, it has been suggested that soils be rated, with respect to nitrogen, phosphorus and potassium availability, in four classes: "high", "medium", "low", and "very low". It has also been emphasized that numerous other factors besides the chemical test should be taken into consideration in such a rating.

It is also necessary to recognize the different fertility levels with respect to the common fertilizer constituents that meet the requirements of the various crops. Crops differ in their abilities to give satisfactory results at a given degree of chemical fertility. This is due in part to actual differences in the amounts utilized by the crops, in part to the indirect effects of the relative concentrations of the various constituents of the active soil system upon the normal functioning of the plant. Economic factors also make it impractical to provide a crop of low acre value with the liberal amounts of "plant food" that may be desirable for maximum yields.

The various common field and vegetable crop plants, for Connecticut conditions, have been arranged in four groups with respect to the practicable minimum fertility levels for the three principal fertilizer constituents. These groupings are shown in Table 5.

TABLE 5. COMMON CROPS OF CONNECTICUT, CLASSIFIED ACCORDING TO RELATIVE REQUIREMENTS FOR VARIOUS FERTILIZER CONSTITUENTS

Requirement Group: A—very high (A+—extra high), B—high, C—medium, D—low (D*—nitrogen supply from legume organisms)

	Nitrogen Requirement Group	Phosphorus Requirement Group	Potassium Requirement Group
Special Crops			
Potatoes, early	A	A	A
" late	B	A	A
sweet	D	C	B
Tobacco	A+	C	A
Vegetable Crops			
Asparagus	A	B	A
Beans, lima or string	D	C	C
Beets, early	A	A	A
" late	B	A	B
Broccoli	B	B	B
Brussels sprouts	B	B	B
Cabbage, early	A	A	A
" late	B	B	B
Carrots, early	B	B	B
" late	C	C	C
Cauliflower, early	A	A	A
" , late	B	B	A
Celery, early	A	A	A
" , late	B	B	A
Corn, sweet, early	B	B	B
" , " late	C	C	C
Cucumbers	B	B	B
Egg Plant	B	B	B
Lettuce, head	A	A	A
" , leaf	B	A	A
Muskmellons	B	B	B
Onions	B	B	B
Parsnips	C	C	C
Peas, early	C	B	B
Pumpkins	C	C	C
Radishes	B	A	A
Rhubarb	B	B	B
Rutabagas	C	B	C
Spinach	A	A	A
Squash, early	B	B	B
" , late	C	C	C
Tomatoes, early	C	B	B
" , late	B	B	B
Turnips	D	B	C
Watermellons	C	C	C
Feed, Hay and Pasture Crops			
Alfalfa	D*	B	B
Barley	C	B	C
Bent grass	C	D	D
Blue grass, Kentucky	C	C	D
Clover, alike	D*	C	C
" , ladino	D*	C	C
" , red	D*	B	B
" , wild white	D*	C	C

	Nitrogen Requirement Group	Phosphorus Requirement Group	Potassium Requirement Group
Corn, field	C	C	C
Grasses, mixed	C	D	D
Oats	B	C	C
Orchard grass	C	C	C
Rye	C	D	D
Rye grass	C	D	D
Timothy	C	D	C
Green Manure Crops			
Buckwheat	C	D	D
Millet	C	D	C
Peas, field Canada	D*	C	C
Rye	C	D	D
Soybeans	D*	C	C
Vetch, hairy	D*	C	C
Fruit Crops			
Apples	C	D	D
Blackberries	D	D	D
Blueberries	D	D	D
Grapes	C	C	C
Peaches	C	D	C
Pears	C	D	D
Raspberries	D	D	D
Strawberries	C	C	D
Nursery Plantings			
Deciduous	C	D	D
Evergreen	D	D	D
Flowers, Annuals	B	B	B
‘‘ , Perennials and Bulbs	C	C	C
Shrubs, Ornamental			
Deciduous	C	C	D
Evergreen	D	D	D
Shade Trees			
Deciduous	C	D	D
Evergreen	D	D	D
Turf			
Lawns, parks and fairways	C	C	D
Playing fields	C	C	D
Putting greens and bowling greens	B	D	D

The amounts of the three principal fertilizer constituents, in terms of pounds of nitrogen (N), "phosphoric acid" (P_2O_5) and "potash" (K_2O) per acre, that would be likely to prove effective on soils of varying nutrient availability classes, for the above crop requirement groups, are shown in Table 6.

TABLE 6. AMOUNTS OF FERTILIZER CONSTITUENTS (N, P_2O_5 OR K_2O), IN LBS. PER ACRE, IN RELATION TO SOIL FERTILITY LEVELS AND CROP REQUIREMENTS

Nutrient Availability Class	Crop Requirement Group			
	A *very high*	B *high*	C *medium*	D *low*
IV — very low	160-180	120-140	80-100	50-70
III — low	120-140	80-100	50- 70	30-40
II — medium	80-100	50- 70	30- 40	10-20
I — high	50- 70	30- 40	10- 20	0

The above amounts are on the basis of broadcast applications. When applied in bands along the rows, according to approved methods of placement, the quantities may be approximately 60 percent of those shown in the Table.

The following examples illustrate the above scheme of estimating desirable fertilizer applications, utilizing both soil tests and other pertinent information.

Case 1. Farmer Jones has a field of well-drained, medium brown, loam soil, in grass sod for several years, occasionally top-dressed with manure. It is to be planted to *field corn,* without additional manure. Fertilizer is to be applied in bands along the row, with a planter of recent model. Soil tests in April are as follows:

pH — 5.2

	Relative Rating Index	Test Designation
Nitrate nitrogen	1.5	very low
Ammonia nitrogen	2.0	low
Phosphorus	1.2	very low
Potassium	4.0	medium
Calcium	2.5	low
Magnesium	1.5	very low
Aluminum	6.0	medium high
Manganese	2.0	low

Lime absorption group: III. *See Table 2.*

Soil reaction preference group, for Corn: C. *See Table 3.*

Liming recommendation at 5.2 pH for III C: **1.2 tons of agricultural limestone, per A** (should be dolomitic because of "very low" magnesium test). *See Table 4.*

Nitrogen availability class: II. *See page —*

Nitrogen requirement group, for Corn: C. *See Table 5.*

Nitrogen recommendation for II C: 30 to 40 lbs. × 0.6 = **18 to 24 lbs. of N per A.** *See Table 6.*

Phosphorus availability class: IV. *See page —*

Phosphorus requirement group, for Corn: C. *See Table 5.*

Phosphorus recommendation for IV C: 80 to 100 lbs. × 0.6 = **48 to 60 lbs. of P_2O_5 per A.** *See Table 6.*

Potassium availability class: II. *See page —*

Potassium requirement group, for Corn: C. *See Table 5.*

Potassium recommendation for II C: 30 to 40 lbs. × 0.6 = **18 to 24 lbs. of K_2O per A.**

Final recommendations: 1.5 tons agricultural limestone, dolomitic broadcast; 500 lbs. of a *4-1-4 fertilizer per acre, drilled in bands.*

Case 2. Farmer Smith has a field of medium dark brown, well-drained sandy loam soil, in potatoes and other cultivated crops for several years, liberally fertilized. A winter cover crop of rye has been plowed under. The field is to be planted to potatoes (Green Mountain variety). The fertilizer is to be drilled in bands. Soil tests last October were as follows:

	Relative Rating Index	Test Designation
pH — 5.0		
Nitrate Nitrogen	2.0	low
Ammonia Nitrogen	1.0	very low
Phosphorus	6.0	medium high
Potassium	4.0	medium
Calcium	2.0	low
Magnesium	3.0	medium low
Aluminum	4.0	medium
Manganese	3.0	medium low

Lime absorption group: II. *See Table 2.*

Soil reaction preference group, for Potatoes: D. *See Table 3.*

Liming recommendation at 5.0 pH for II D: **0.5 tons of limestone per A.** (interpolated). *See Table 4.*

Nitrogen availability class: IV. *See page —*

Nitrogen requirement group, for Potatoes: B. *See Table 5.*

Nitrogen recommendation for IV B: 120 to 140 lbs. × 0.6 = **72 to 84 lbs. of N per A.** *See Table 6.*

Phosphorus availability class: II. *See page —*

Phosphorus requirement group, for Potatoes: A. *See Table 5.*

Phosphorus recommendation for II A: 80 to 100 lbs. × 0.6 = **48 to 60 lbs. of P_2O_5 per A.**

Potassium availability class: III. *See page —*

Potassium requirement group for Potatoes: A. *See Table 5.*

Potassium recommendation for III A: 120 to 140 lbs. × 0.6 = **72 to 84 lbs. of K_2O per A.** *See Table 6.*

Final recommendations: 1000 lbs. of agricultural limestone, broadcast; 1200 lbs. of 7-7-7 fertilizer, per A., drilled in bands.

The mechanics of such a scheme for using soil tests and other information as a guide to recommend treatments is obviously somewhat cumbersome. However, it is to be used chiefly as a means of systematizing one's reasoning in applying soil tests to practical problems. After a number of cases have thus been worked out in detail, the soil diagnostician will arrive at the final recommendations by subconscious recognition of all the various stages that must be "thought through" in order to arrive at a reasonably sound result.

SUMMARY

THE soil testing methods developed at this Station during the past 10 years have been built around the employment of a half-normal acetic acid solution, buffered at 4.8 pH with sodium acetate, for the soil extraction. This has been designated, for convenience, as the "Universal" soil extracting solution. This scheme of testing, identified as the "Universal Soil Testing System", has been found to be of great value in chemical soil diagnosis, not only in this State, but in many sections of the United States as well as numerous other countries.

The revised methods used in these tests are presented in detail. Routine tests, of general application, are as follows: nitrate and ammonia nitrogen, phosphorus, potassium, calcium, magnesium, aluminum, and manganese. Special tests provide indications relative to the following constituents: Iron (both ferric and ferrous), sulfates, nitrites, sodium, chlorides, carbonates, boron, zinc, copper, mercury, lead, and arsenic.

The adoptions of the tests to plant tissue testing, the examination of drainage and irrigation waters and other dilute aqueos solutions, and the testing of saline and alkali soils are also presented.

Considerations involved in the practical interpretation of the tests, under various conditions, are discussed at length. A systematic scheme for applying these interpretations in estimating fertilizer needs is proposed.

Details of simple pH testing are also included. The significance of soil reaction with respect to lime requirement, and the interpretation of quick chemical tests is given due attention.

The modifying effects of physical soil properties and other factors limiting crop growth are also stressed.

Methods such as these described in this bulletin are capable of yielding valuable information concerning the chemical characteristics of the soil and are extremely helpful when interpreted by a person who is otherwise competent to offer sound advice in soil management practices.

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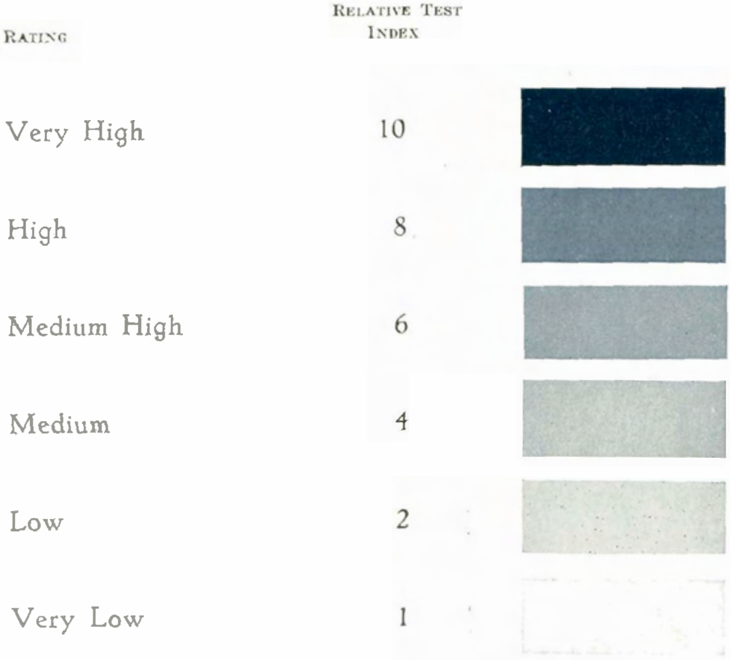
PLATE I.

NITRATE NITROGEN COLOR CHART

Universal Soil Testing System



Rating	Relative Test Index
Very High	10
High	8
Medium High	6
Medium	4
Low	2
Very Low	1

PLATE II.

AMMONIA NITROGEN COLOR CHART

Universal Soil Testing System

Rating	Relative Test Index
Very High	10
High	8
Medium High	6
Medium	4
Low	2
Very Low	

PHOSPHORUS COLOR CHART

Universal Soil Testing System

Rating	Relative Test Index
Very High	10
High	8
Medium High	6
Medium	4
Low	2
Very Low	1

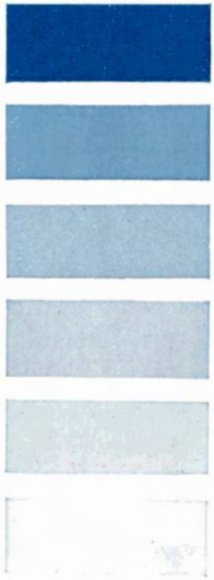


PLATE IV.

POTASSIUM READING CHART

Universal Soil Testing System

RATING	RELATIVE TEST INDEX
Very High	10
High	8
Medium High	6
Medium	4
Low	2
Very Low	

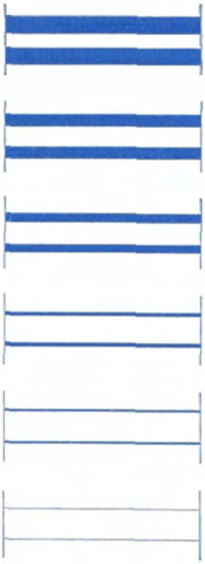


PLATE V

CALCIUM READING CHART

Universal Soil Testing System

RATING	RELATIVE TEST INDEX
Very High	10
High	8
Medium High	6
Medium	4
Low	2
Very Low	1

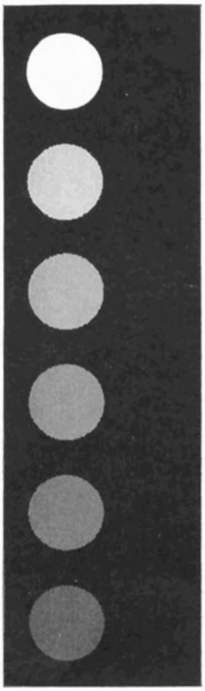


PLATE VI.

MAGNESIUM COLOR CHART

Universal Soil Testing System

(using Reagent A-2 (Titan Yellow)

RATING	RELATIVE TEST INDEX	
Very High	10	🟥
High	8	🟥
Medium High	6	🟧
Medium	4	🟧
Low	2	🟧
Very Low	1	🟧

ALUMINUM COLOR CHART

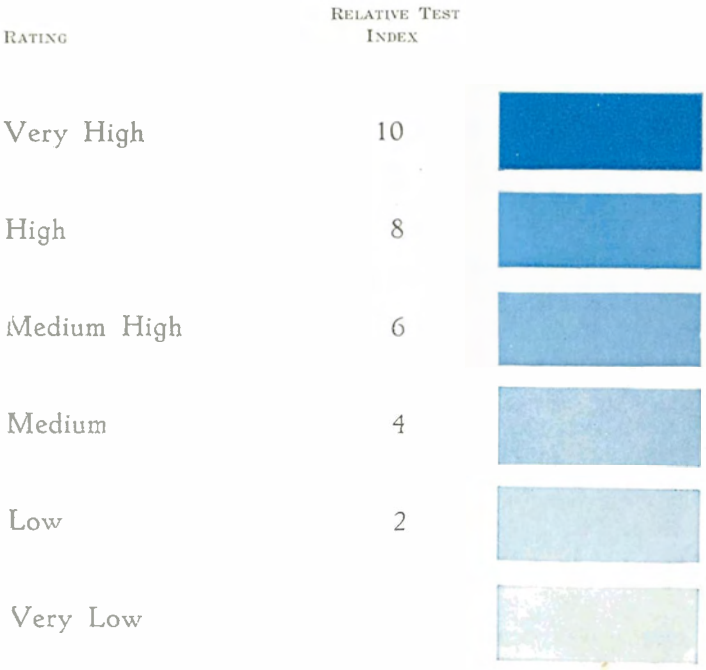
Universal Soil Testing System

Rating	Relative Test Index
Very High	10
High	8
Medium High	6
Medium	4
Low	2
Very Low	

PLATE VIII

MANGANESE COLOR CHART

Universal Soil Testing System



Rating	Relative Test Index
Very High	10
High	8
Medium High	6
Medium	4
Low	2
Very Low	