Soils

Bulletin 392 **March, 1937**

THE UNIVERSAL SOIL TESTING SYSTEM

(A Revision of Bulletin 372)

M. F. MORGAN

Connecticut
Agricultural Experiment Station
New Haven

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ERRATA

Bulletin 392: The Universal Soil Testing System

[redacted] e 136, under copper reagent: Change "alphabenzoinamine" to "alphabenzoineoxime".

Page 140, line 28: Change "special" to "supplemental".

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Agricultural Experiment Station
New Haven

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THE UNIVERSAL SOIL TESTING SYSTEM

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M. F. MORGAN

The methods embodied in Bulletin 372 of this Station have been in constant use by the Soils Department at New Haven, the Tobacco Substation at Windsor and the Extension Service, Connecticut State College, Storrs, since their publication in June, 1935. Numerous other experiment stations, agricultural colleges and private individuals have employed these tests with helpful results. The widespread demand for Bulletin 372 has exhausted the supply much sooner than was anticipated. Since a few minor changes and additions in the methods and their interpretation have been developed, it is deemed advisable to issue a revision of the above publication.

The distinguishing characteristic of this scheme of testing is the employment of a highly buffered mixture of acetic acid and sodium acetate for the extraction of the soil sample. All of the significant tests are conducted on portions of this extract; hence great speed and economy of operation are provided.

THE CHOICE OF A SOIL EXTRACTING SOLUTION

Most of the various simple soil tests devised during recent years have been conducted as single tests, with a separate soil extraction for the constituent in question. Hence the selection of a suitable agent for bringing into solution measurable amounts of the element or chemical radical to be studied was determined by the characteristics of that constituent in its liberation from the soil. However, investigators have differed in their choice for any one test. A brief review of the current situation is pertinent.

Phosphorus is the element most extensively studied by quick tests. Spurway[1] first used both dilute nitric acid solution and pure distilled water for this test. In his more recent method[2] he uses a dilute acetic acid solution of approximately .028 N. concentration in extraction of the soil for phosphorus and other tests. Truog[3] used a .002 N. solution of sulfuric acid, buffered at 3 pH with ammonium sulfate. Bray[4] used hydrochloric acid and ammonium molybdate of approximately 0.7 N. acid concentration. Harper[5] suggested the use of 0.1 N. acetic acid. Dahlberg and Brown[6] used a 0.25 N. sodium hydroxide titrated to 5 pH with acetic acid, thus giving a final mixture of 0.25 M. sodium acetate and approximately .08 N. acetic acid. Hockensmith, Gardner and Goodwin[7] employed a 1 percent solution of potassium carbonate. Thornton[8] proposed a .4 percent solution of ammonium molybdate in approximately 0.8 N. hydrochloric acid.

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[1] Tech. Bul. 101, Mich. Agr. Exp. Sta.
[2] Tech. Bul. 132, Mich. Agr. Exp. Sta.
[3] Jour. Am. Soc. Agron. 22: 874–882
[4] Bul. 337, Ill. Agr. Exp. Sta.
[5] Science 76: 415–416
[6] Jour. Am. Soc. Agron. 24: 469–476
[7] Tech. Bul. 2, Col. Agr. Exp. Sta.
[8] Circ. 204, Ind. Agr. Exp. Sta.

The preceding summary illustrates the range of conditions under which phosphorus is being extracted for conducting this test. It is obvious that the conditions of solubility vary widely.

The amounts of phosphates liberated from the soil by an extracting solution depend upon the following factors:

1—The total acid concentration of the extracting solution.
2—The hydrogen-ion concentration (pH) of the extracting solution.
3—The nature of the anions in the extracting solution.
4—The ratio of the extracting solution to the soil.
5—The time of exposure of the soil to the action of the extracting solution.
6—The chemical combinations in which phosphates occur in the soil.
7—The total amount of phosphorus in the soil.

Any chemical method of determining the active phosphorus in the soil is thus highly empirical in nature, and the quantitative results obtained are dependent upon the relationship of the particular extracting solution to the above factors.

In a test for active potassium Bray[1] first used an extraction with a solution of 2.4 N. nitric acid concentration containing sodium acetate to 2.4 molarity. He has since[2] reduced these concentrations to some degree. Spurway[3] uses the acetic acid extraction for his potassium test, as described for his more recent phosphorus and other tests. Thornton[4] employs a solution containing sodium cobaltinitrite, sodium nitrate and acetic acid adjusted to 5 pH.

The majority of quick tests for ammonia nitrogen, potassium, calcium, magnesium and manganese are based on the principle of base exchange. Thus hydrogen, sodium or other cations in the extracting solution replace the basic constituents absorbed by the active soil colloids, liberating them into the soil extract. In order to determine all of the replaceable bases, it is necessary to leach the soil with a number of successive portions of the extracting solution. This requires a considerable amount of time, and the resultant extract becomes too dilute for detection by the usual microchemical tests, unless the soil is especially high in the exchangeable base in question. Therefore it is necessary to assume that the amount of base liberated into the first portion of the extracting solution represents a reasonably definite ratio of the total amount removable.

The extracting solution also removes water soluble bases contained in the soil, but these are usually negligible as compared with the amounts held in exchangeable form. When the soil contains lime or dolomitic carbonates, the extract may derive its calcium and magnesium in part from these materials rather than from base exchange reactions with the colloidal complex. This is particularly true when the extracting solution contains free acid. However, calcium and magnesium carbonates, when present, are a source of these bases for future replenishment of losses of exchangeable bases. If the hydrogen-ion concentration of the extract is not excessive, only the readily decomposable, fine particles and films of carbonates will be attacked during the few minutes of contact between the soil and the extracting solution.

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[1] Jour. Am. Soc. Agron. 24: 312–316
[2] Information supplied in correspondence
[3] Tech. Bul. 132, Mich. Agr. Exp. Sta.
[4] Circ. 204, Ind. Agr. Exp. Sta.

Soils of slight acidity or alkalinity liberate only small traces of aluminum or iron to extracting solutions containing dilute acids, especially when suitably buffered. Under more acid soil conditions, some aluminum enters a more active state, capable of becoming partially water soluble under field conditions when the pH of the soil solution is 5.0 pH or lower. This may also be true of iron, particularly in the presence of large amounts of organic matter and with imperfect drainage conditions. An extracting solution for the determination of these elements, which is well buffered between 4 and 5 pH, is most suitable for the estimation of these forms of aluminum and iron.

Nitrates, nitrite nitrogen and soluble sulfates contained in the soil are capable of complete extraction by water or aqueous solutions. Therefore any extracting solution that does not contain ions interfering with the development of the test may be employed.

The Universal soil extracting solution used for the tests described in this publication possesses the following characteristics which appear to justify its selection:

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 required 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.

Other methods have been proposed for the estimation of several constituents in the liquid resulting from a single soil extraction. These differ with respect to the type of solution used for making the extract, and in numerous points of technique.

Spurway, in his more recent publication[1] describes a procedure based on the solvent action of very dilute acetic acid (approximately 0.025 N.) and introduces supplementary methods for "reserve" potassium, iron, manganese and phosphorus involving an extraction with 0.135 N. hydrochloric acid.

Hester[2] has developed methods along similar lines to those followed by the author, except that he employs a soil extracting solution with a total acetic acid concentration of 0.2 N. buffered with sodium acetate at 5.0 pH.

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[1] Tech. Bul. 132 (Revised) Mich. Agr. Exp. Sta.
[2] Mimeographed publication issued by Va. Truck Exp. Sta., March, 1936.

Thomas[1] uses the Universal soil extracting solution, but has made a number of minor variations in details of technique.

Bray[2] has introduced a provisional procedure based upon the extraction of the soil with a 25 percent solution of sodium perchlorate. He asserts that this removes the exchangeable potassium more completely than does a sodium acetate-acetic acid buffer mixture, especially on soils of high base exchange capacity. However, preliminary studies by the author have not shown any special advantages in this method. Also, the solution is difficult to prepare and relatively expensive. Further trials on a wide range of soils should be conducted before this interesting proposal can be generally accepted.

The Hellige-Truog "combination soil tester", developed by Truog[3] also uses a single extraction for the making of several tests. The commercial character of this set has apparently prevented the publication of the constitution of the soil extracting solution employed.

In view of the variations in solvent action and in ratio of soil to extracting liquid inherent in the numerous schemes for rapid chemical soil tests, it is obvious that differences in results by various methods are inevitable. It is also probably true that a particular test may be superior when employed on soils that are like those most familiar to the person who has developed it, although it may fail to give results in harmony with known crop response on a soil of entirely different physical character and fertility level. As will be discussed later, the interpretation of any test must be based upon the normal characteristics of the soils of a particular region, with respect to the crop in question.

THE SOIL SAMPLE

The Universal soil testing system requires a final sample of only a teaspoonful of soil. There are nearly two hundred million times this amount in an acre of soil. Hence the necessity for accurate sampling cannot be too greatly emphasized.

If the purpose of the soil test is to reveal average conditions existing in the field or plot of ground in question, the sample should be a thorough mixture of equal amounts collected at twenty or more points, fairly distributed over the area in question. On the other hand, if there is a special condition to be studied, such as the local soil variation or spot of ground upon which plant growth is abnormal, the sampling should be confined to that area. In such cases a separate sample from the normal part of the field should also be collected.

For sampling cultivated fields an auger is a convenience. It should be bored into the soil about six inches and drawn out with a straight upward pull. The soil may then be stripped from the spiral grooves into a clean pail. If a considerable amount of sampling is to be done, a shank about three feet long with a T-shaped handle of gas pipe should be welded to the auger bit. It is preferable to have screw tip and cutting flanges of the bit removed, so that the cutting face may be beveled downward.

If an auger is not available, the sample may be taken with a trowel, shovel or spade. A vertical cut is made to the depth of six or seven inches, and the face is sliced down for the sample.

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[1] Mimeographed publication issued by Agronomy Dept., University of Maryland, Jan., 1936

[2] Mimeographed publication issued by Agronomy Dept., University of Illinois, Dec., 1936

[3] Trade circular, "Soil Testers", issued by Hellige, Inc.

In sampling permanent pasture sod and greensward, the surface soil sample should be taken to a depth of only two inches. If desired, separate samples from greater depths may be collected also.

The vessel in which the various sub-samples are collected should then be dumped over a sheet of heavy cloth or tough paper, picked over or run through a one-quarter inch mesh screen for removal of stones and coarse roots, and carefully mixed. The final sample, which need not weigh more than a few ounces, should be drawn from the bulk sample by repeated quartering.

If possible the sample should be taken when the soil is not abnormally wet and sticky, since it is difficult to mix when in this condition.

The final sample may be brought or sent to the testing laboratory in any clean and reasonably tight container, which has not previously contained drugs, cosmetics, chemicals or fertilizers.

Time of sampling: The soil is a dynamic body, teeming with microorganisms 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 and will be discussed in the section on 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.

Soil records: In order that soil diagnosis may be as complete as possible, information in regard to past treatment of the field with respect to fertilizers, manure and lime, the performance of previous crops, and the crops to be grown in the immediate future, should be at hand. It is also necessary to know the characteristics of the soil type, especially with respect to texture, drainage and organic content. If the area from which the sample is drawn is shown on a soil map, tests may be most reliably interpreted in relation to the special characteristics of the soil type. A form is given in Circular 89 of this Station which, if carefully completed by the sampler, supplies the needed information to the person reporting the results of the tests.

Soil testing service: No single agency in this or any other state is in a position to make complete tests of every field on every farm. This is not necessary, since carefully selected tests of representative conditions under the various cropping systems on the important soil types supply information applicable to normal conditions. Such data are available to the farmer or gardener through the extension service in any region. A healthy person does not consult the physician except for an occasional physical examination, and the same principle applies in soil fertility practice. The agricultural extension service, through the county agents and agronomy specialists, is the first line of contact with the farmer in this work. High school teachers of agriculture may also offer helpful assistance in their communities. Commercial organizations, such as fertilizer and lime companies, that are conscientiously striving to serve their clients, are giving increased attention to soil testing. The State Experiment Station is interested in diagnosing any unusual soil trouble, and offers its services to all who cannot be provided for through the above agencies.

Circular 89 of this Station gives information in regard to collecting and submitting soil samples for testing. This service is available to all citizens of Connecticut on samples received at the following places: Soils Department, Connecticut Agricultural Experiment Station, New Haven; Tobacco Substation, Windsor; Agronomy Extension Office, Connecticut State College, Storrs.

Preparing the soil sample for testing: The entire sample received for testing should be passed through a 2 mm. or 10-mesh screen. If too wet to be screened easily, the soil should be permitted to dry out to a mellow-moist condition first. After screening, it should be mixed thoroughly. The sample should be kept in a room that is free from strong laboratory fumes. It should be tested as soon as possible after collection in the field. Best results are obtained on soils containing some of their natural moisture. However, samples to be reserved for future testing should be carefully air dried before storing in air-tight containers.

PREPARATION OF SOLUTIONS AND REAGENTS

(All chemicals should be of good C.P. grade)

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 one liter. This solution is approximately 0.5 N. in total titrable acidity, and is buffered at 4.8 pH.

Reagents for Routine Tests

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 four drops are added to one 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 also should 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 four drops of the "Universal" leaching solution, should give a practically colorless spot.

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.

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 acidified 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.

Calcium reagent: A saturated solution of sodium oxalate.

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 0.15 gm. of Titan yellow (Dr. G. Grübler & Co. or similar quality) 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.

Aluminum reagent: Dissolve 0.05 gm. of hematein in 100 ml. of 95 percent ethyl alcohol. *This should be freshly prepared at least once a month.*

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": Dissolve 15 gms. of sodium hydroxide in 100 ml. of distilled water. This reagent is the same as magnesium reagent "B". (See below.)

Manganese reagent, supplemental: A saturated solution of potassium periodate in the Universal soil extracting solution.

Reagents 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 soil extracting solution: Make up 30 ml. of glacial acetic acid to one liter, by addition of distilled water. This solution is approximately 0.2 normal in total acidity.

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.; acetic 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.

Special chlorine extracting solution: Dilute 13 ml. of nitric acid of ordinary C. P. concentration (70 percent) to one liter, using distilled water. This solution is approximately 0.2 N. in total acidity.

Chlorine 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 gm. 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 thiocyanate 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 alphabenzoinamine in 100 ml. of ethyl alcohol (95 percent).

APPARATUS AND GLASSWARE

The following list itemizes the equipment normally required for conducting the routine tests used in the Universal soil testing system, and provides for testing six samples of soil simultaneously. Where specifications are given, they should be exactly followed.

1 Large supply bottle for Universal soil extracting solution.
2 Spot plates, for color reactions, with 12 depressions, 20 mm. diameter and ~~0.75~~ mm. deep. 7.5
12 Glass vials, 50 mm. long, 10 mm. inside diameter.
1 Block, containing 12 holes ½ inch in diameter and 1 inch deep, for supporting test vials.
6 Eyedropper pipettes, with unflattened straight tip of 2 mm. diameter.
6*Funnels, short neck, 4 cm. diameter.
6*Erlenmeyer flasks, 50 ml.
1 Filter paper, box of 100 sheets, Munktell No. 0, 9 cm. diameter.
1 Test tube brush, puff-tuft, for ½ inch diameter tubes.
6 Glass rods, 4 inches long.
1 Measuring cylinder, 10 ml.
1 Measuring spoon, teaspoon size.
1 Dropping bottle, glass-stoppered, for nitrate reagent.
3 Dropping bottles, 2 oz. rubber bulb stopper for Universal soil extracting solution, 15 percent NaOH and 1:1 hydrochloric acid, HCl.
9 Dropping bottles, 1 oz. rubber bulb stopper, for other test reagents.
Additional dropping bottles should be provided for the reagents used in the special tests, if desired.

PROCEDURE FOR CONDUCTING THE TESTS

The soil extraction: Insert the stem of the funnel into the neck of the flask or bottle used for the collection of the soil extract, and fit a folded filter paper of 9 cm. diameter (of Munktell No. 0, C. S. and S. No. 589 or similar grade) into the funnel.

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 solution, 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 procedure: Place a teaspoonful of soil, gently packed and leveled, into a 30 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 above directed.

Soils of some areas are not rapidly saturated with the soil extracting solution, when the extraction is conducted directly in the filter cone. This is especially true of heavy clay soils, particularly when they are already

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*Special soil filtering tubes, with funnel mouth, may be substituted for these items.

partially wet with field moisture. In such cases it is difficult to obtain concordant results on separate determinations of the same sample, and it is preferable to follow the suggested alternate procedure. However, one or the other method should be consistently followed. The results obtained, while usually relatively the same, are not directly comparable.

Nitrate nitrogen test[1]: Transfer one drop of soil extract to the spot plate. Add four 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 prolonged standing in excess of two minutes, but for convenience of operation, the charts are standardized on the basis of this time.

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

Two drops of the reagent are needed to insure neutralization of the acidity of the extract, permitting the development of a permanent color.

Phosphorus test[3]: Transfer 10 drops of the soil extract to the spot plate. Add one drop of reagent "A" and two 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. The true color is slightly less dark than shown.

If more than one drop of reagent "A" is added, the test is abnormally high. If more than two drops of reagent "B" are used, or if that reagent contains more than 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.

Soils which have been heavily treated with soluble mercury compounds for control of insects or fungous diseases may give a dark precipitate on the addition of reagent "B" in the phosphorus test. Such a result, while valuable in suggesting the presence of mercury, completely prevents identification of phosphorus.

Soils which have been heavily treated with arsenic compounds in the control of insect troubles may give unreliably high apparent tests for phosphorus. Amounts of arsenic entering the soil as spray residues have not appeared to be sufficient to affect the reliability of the test.

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.

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[1] This is adapted from a previous nitrate test described by the author—Science 71:343.
[2] This is adapted from the original Nessler test for ammonia
[3] This is adapted from the ceruleo-molybdate test of Denigès—Compt. Rend. Soc. Biol., 84:875.

Potassium test[1]: Transfer 10 drops of the soil extract to the test vial (10 mm. inside diameter). Add one drop of reagent "A" and eight 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 one 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. If no perceptible turbidity is obtained, the test is obviously lower than in the case of a very slight turbidity which is not sufficient to obscure the faintest lines on the chart, and should be so recorded.

In general, a soil giving only faint traces of turbidity is recorded as "very low" (100 lbs. per acre), while a negative test, showing no perceptible milkiness, is indicated as "extra low" (50 lbs. per acre). The chart given in this bulletin is not sufficiently delicate for such differentiations.

Calcium test[2]: Transfer 10 drops of the soil extract to the test vial. Add one 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[3]: Transfer 10 drops of the soil extract to the spot plate. Add one drop of reagent "A-2" and three 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"[4], 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.

Aluminum test[5]: Transfer two drops of the soil extract to the spot plate. Add two drops of the Universal soil extracting solution and one drop of the reagent. Let stand one minute, and compare the resultant yellow, brownish yellow to lavender color with the chart. The true bottom color is slightly more orange yellow than shown.

If a "dirty" blue-gray color results from this test, it is indicative of abnormal concentrations of active iron; hence a supplemental test for this constituent should be made.

After completing the reading, add one drop of 1:1 hydrochloric acid (equal parts of C. P. hydrochloric acid and distilled water) and shake the block gently before washing it. This prevents the formation of a stain on the porcelain which may interfere with subsequent tests.

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[1] This is adapted from the procedure suggested by Bray—Jour. Am. Soc. Agron. 24:312.
[2] This is adapted from the test suggested by the author—Conn. Agr. Exp. Sta. Bul. 333.
[3] This is adapted from the test used by Spurway—Tech. Bul. 132, Mich. Agr. Exp. Sta.
[4] This is adapted from the test suggested by Feigl—Emich-Schneider, Microchemical Laboratory *Manual*, J. Wiley and Sons. It was first used by the author as a soil test. To avoid confusion with previously issued instructions, the reagent is designated "A-1".
[5] This is adapted from the test previously used by the author—Conn. Agr. Exp. Sta. Bul. 333.

The reagent in this test deteriorates slowly, and should be freshly prepared every four weeks.

Manganese test[1]**:** Transfer 10 drops of the soil extract to the spot plate. Add one drop of reagent "A", stir and add one 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. The true color is a slightly greener blue than shown.

If more than one drop of reagent "B" is added, or if the tip of the pipette used in transfering that reagent is abnormally large, the test may fail, since too much alkalinity interferes with the test. This test, if properly conducted, is extremely sensitive.

If no perceptible blue color is detected, add two drops of the supplemental manganese reagent. 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 two 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 two pounds per acre. If the color is green, gradually changing to yellow, this is recognized as "trace plus", or approximately three pounds per acre. If any blue color whatsoever was apparent in the previous stage of testing, a deep yellow to orange-yellow color now develops almost at once.

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

If a comparatively high reading was originally obtained, it may be desirable to confirm it with a further test involving a separate procedure, as follows:

> Transfer 10 drops of the reagent to the spot plate and add two drops of the "special" manganese reagent. Stir briskly for two minutes and let stand for two minutes. A rose or lavender color, resulting from the development of permanganate, indicates an abnormally high concentration of active manganese in the soil. No chart for this test is included.

If the soil contains abnormal concentrations of nitrite nitrogen, a brownish yellow discoloration is to be noted in the routine manganese test. In this case a supplemental nitrite test should be made.

SPECIAL SUPPLEMENTAL TESTS

Iron test (both ferric and ferrous): Transfer 10 drops of the reagent to the spot plate. Add three drops of reagent "A" (1:1 HC1) and one drop of reagent "B". Stir, let stand two minutes. The resultant colors indicate amounts approximately as follows:

Color	Test	Approximate Amount per acre of surface soil
Blue	very high	500 lbs.
Blue green	high	250 lbs.
Apple green	medium high	100 lbs.
Pale green	medium	50 lbs.
Greenish yellow	low	25 lbs.
Lemon yellow	very low	10 lbs.

No chart for this test is shown in this bulletin.

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[1] This is adapted from the test described by Feigl—Emich-Schneider: Microchemical Laboratory Manual, J. Wiley and Sons, p. 162.

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 three drops of reagent "A" and one drop of reagent "B". Stir and let stand two minutes. The resultant colors represent amounts approximately as follows:

Color	Test	Approximate Amount per acre of surface soil
Deep brownish red	very high	300 lbs.
Medium brownish red	high	200 lbs.
Pale brownish red	medium high	75 lbs.
Very pale brownish red	medium	40 lbs.
Slight reddish tint	low	15 lbs.
Very faint reddish tint	very low	5 lbs.

No chart for this test is shown in this bulletin.

Ferrous iron test: Transfer 10 drops of the soil extract to the spot plate. Add two drops of reagent "A" and one 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).

Sulfate sulfur test: Transfer 10 drops of the soil extract to the test vial. Add one drop of the reagent. Shake vigorously and let stand for five minutes. Compare with the calcium chart. Pounds per acre are approximately one-fifth those indicated for corresponding calcium tests.

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 nitrogen test: Transfer 10 drops of the soil extract to the spot plate. Add one drop of the nitrite reagent, one drop of hydrochloric acid (1:1) and four drops of magnesium reagent "B" (15 percent NaOH). Stir and let stand one minute. The resultant colors represent amounts approximately as follows:

Color	Test	Approximate Amount per acre of surface soil
Yellowish orange	very high	50 lbs.
Orange yellow	high	25 lbs.
Lemon yellow	medium	10 lbs.
Pale yellow	low	5 lbs.
Trace of yellowish tint	very low	2.5 lbs

No chart for this test is included in this bulletin. Soils very rarely show readable nitrite tests under field conditions; hence this test is not used in the routine procedure.

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

Transfer four drops of the extract, thus obtained, to a test vial. Add 20 drops (one ml.) of the reagent. Shake vigorously at one minute intervals for 10 minutes and compare with the potassium chart. The amounts in pounds per acre are approximately 10 times those indicated for potassium.

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: 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 one drop of the reagent. Shake vigorously, and compare the resultant turbidity with the calcium chart. The amounts in pounds of chlorine per acre are approximately as follows, when read on the calcium chart, from top to bottom: 4000-2500-1500-500-250-125.

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 alkaline reagent (Ammonia reagent or magnesium reagent "B"). Normally this precipitate does not interfere with the color reactions and is due to the formation of calcium hydroxide in excess of its solubility.

Boron test: Extract one level *tablespoonful* of soil, in a folded filter cone with 10 ml. of the Universal soil extracting solution. Transfer 10 drops of the extract to a spot plate depression. Add two drops of reagent "A" and 10 drops of reagent "B". Stir thoroughly until a uniform color is obtained. A clear golden 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. When this is just perceptible, the boron content of the soil is about four pounds per acre, an amount that should be adequate for normal growth. If a fairly deep red color develops, boron may be present in amounts sufficient to produce injury. It is suggested that the test be calibrated by standard amounts of boron, as boric acid, dissolved in the Universal soil extracting solution.

Zinc test[1]**:** Prepare the soil extract in the same manner as for the boron test. Transfer 10 drops of the extract to a glass test vial (10 by 50 mm.). Add four 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 occasionally found in the vicinity of industrial plants processing zinc ore or metal.

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[1] This is adapted from the methods of Krumholz and Sanchez. Mikrochemie 15:114.

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 above 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., and 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 should be especially useful in examining soils with considerable accumulations of spray residues.

SPECIAL PRECAUTIONS

All glassware, test blocks, stirring rods, etc., should be washed with clean tap water and rinsed with distilled water immediately after being used. 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.

Beginners in soil testing should make repeated tests on a number of soils differing widely in fertility, before attempting to make any conclusions based on the results of single tests.

CALIBRATION OF CHARTS

The charts and scales of readings given in this bulletin are based on the relationships between the amount extracted by the first 10 ml. portion passing through the soil sample and the total amount recovered by a series of 20 successive extracts. This relationship has been found to be reasonably constant for a number of soils. On this basis, the first extract repre-

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[1] This is adapted from the method of Hosking. Jour. and Proc. Austral. Chem. Inst. 1936: 172

sents the following percentage of the sum in the successive extractions, for the various constituents:

> 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.

In the above connection, it is of interest to note that practically all of the nitrates 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 concentration 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.

Using a proportion of one teaspoonful (the equivalent of 5 gms. of soil of normal volume weight) to 10 ml. of extracting solution, it is thus possible to calibrate the amounts in terms of pounds per acre in the soil by the use of the above relationships. Thus, if 5 gms. of soil give to 10 ml. of extracting solution a concentration of 20 parts per million, 40 parts per million of soil are liberated by the first extract, or 80 pounds per acre of normal surface soil. If only 50 percent of the total extractable material is set free by the first extraction, then the total is 160 pounds per acre.

Determinations made on the above basis are of the same order of magnitude as results obtained in accepted laboratory determinations for nitrates, ammonia nitrogen, phosphorus, potassium, etc. In general, low tests show somewhat smaller numerical values by this scheme of estimation than by laboratory procedure. Results in the middle range of the charts are usually as close as can be expected from such a system of ocular approximation.

Since the soil sample is by volume rather than by weight, the amounts in terms of pounds per acre of surface soil are independent of the volume weight of the soil.

The use of descriptive terms, such as "high," "medium" and "low" is convenient to show relative amounts of active forms of the various constituents in the soil. However, this should not be construed as indicating directly that a soil is deficient for the crop in question. Thus a soil giving a low phosphorus test may be sufficiently high in the availability of this element for rye or similar crops, but is doubtless deficient for tobacco or alfalfa. This will be considered in the section on interpretations.

COMPOSITE SOLUTION STANDARDS

The color and turbidity charts given in the last sheets of this bulletin are the results of the best efforts of the engraver and printer. However, it is very difficult to obtain true reproductions by the photo-engraving process. Hence it is desirable to provide a means of checking them with solutions containing a range of concentrations of the various constituents determined in the routine tests.

The following scheme employs a series of stock solutions containing each of these constituents. Aliquot portions are used for the preparation of composites which give approximately the same relative levels of concentration for the various tests.

Preparation of Stock Solutions

Nitrate nitrogen: 0.607 gms. sodium nitrate ($NaNO_3$) diluted to 100 ml. with the Universal soil extracting solution.

Ammonia nitrogen: 1.180 gms. ammonium sulfate $(NH_4)_2SO_4$ diluted to 100 ml. with the Universal soil extracting solution.

Phosphorus: 0.045 gms. mono-sodium phosphate ($NaH_2PO_4.H_2O$) diluted to 100 ml. with the Universal soil extracting solution.

Potassium: 0.764 gms. potassium chloride (KCl) diluted to 100 ml. with the Universal soil extracting solution.

Calcium: 8.808 gms. calcium acetate ($Ca(C_2H_3O_2)_2.H_2O$) diluted to 100 ml. with the Universal soil extracting solution.

Magnesium: 1.766 gms. magnesium acetate ($Mg(C_2H_3O_2)_2.4H_2O$) diluted to 100 ml. with the Universal soil extracting solution.

Aluminum: 1.782 gms. aluminum chloride ($AlCl_3.6H_2O$) diluted to 100 ml. with the Universal soil extracting solution.

Manganese: 0.203 gms. manganese sulfate ($MnSO_4.4H_2O$) diluted to 100 ml. with the Universal soil extracting solution.

Preparation of Composite Solution Standards

Aliquots of stock solutions for dilution to 200 ml. with Universal soil extracting solution, in ml.

	"High" standard	*"Medium" standard*	*"Low" standard*
Nitrate Nitrogen	2.0	0.6	0.2
Ammonia Nitrogen	2.0	0.6	0.2
Phosphorus	2.0	0.6	0.2
Potassium	2.0	1.0	0.6
Calcium	4.0	2.0	1.0
Magnesium	2.0	0.6	0.2
Aluminum	2.0	0.6	0.2
Manganese	3.0	1.0	0.4

Appropriate portions of the above composite solution standards should be tested in the same manner as for soil extracts, in order to familiarize the operator with the true colors or turbidity corresponding with the above levels of concentration.

SOIL REACTION

The degree of soil acidity or alkalinity, in terms of pH, is not determined by the series of tests described in this bulletin. However, a measurement of pH should be made, since the reaction of the soil is essential to proper interpretations of these tests and is a valuable phase of soil diagnosis. When only a small number of samples are to be tested at one time, a colorimetric method, such as was described by the author in Bulletin 333 of this Station, is satisfactory for all practical purposes. However, if large numbers of soils are to be studied, an electrometric method of pH measurement is preferable in routine determinations. The "quinhydrone electrode" type of apparatus is most convenient but is subject to error on soils containing oxidizing materials such as manganese dioxide. The more recent "glass electrode" apparatus is especially reliable, and in the hands of a skilled manipulator, is rapid and highly accurate.

INTERPRETATION OF THE TESTS

pH

For convenience in the discussion of the relationship between soil reaction and crop needs, the common crops grown in Connecticut are grouped as follows:

SOIL REACTION PREFERENCE GROUPS

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

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 5.6 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 5.4 pH in order to protect them from scab. The plants marked with a dagger (†) are usually adversely affected by reactions above 5.4 pH.

Recommendations as to liming are based upon the following factors: pH; the soil type, especially with reference to its texture and organic content; the calcium, magnesium, aluminum and manganese tests; the soil reaction preferences of the crop.

For convenience in tabulation, recommendations are based on steps of 0.4 pH. Intermediate values may be interpolated.

Soils are grouped as follows, as related to amounts of lime needed at a given pH:

I—very sandy, light colored soils.
II—medium brown or grayish brown sandy soils and light colored loams.
III—dark colored sandy soils, medium brown or grayish brown loams and light colored silt loams.
IV—dark colored loams, medium brown or grayish brown silt loams and light colored clay loams.

The color is that of the dry soil. Some allowance should be made for darkening due to moisture. Soils high in organic matter darken more when moist than those low in organic matter.

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 or very low magnesium tests should be limed with dolomitic (magnesian) lime if the pH test indicates that lime is needed. If the pH is sufficiently high 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.

The following table 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

LIMING TABLE

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

#—Crops of this group not recommended at this pH.
*—Fertilizers with an acid residual effect should be used.
O—Neutral fertilizers preferable.
X—Fertilizers with an alkaline residual effect should be used, or very light liming is optional.

SOIL TYPE I
Crop group

	A	B	C	D
7.2	O	*	#	#
6.8	O	O	#	#
6.4	X	O	*	#
6.0	.5	X	O	*
5.6	1.0	.5	O	*
5.2	1.4	1.0	.5	O
4.8	1.8	1.4	1.0	.5
4.4	2.1	1.8	1.4	1.0
4.0	2.3	2.1	1.8	1.4

SOIL TYPE II
Crop group

	A	B	C	D
7.2	O	*	#	#
6.8	O	O	#	#
6.4	X	O	*	#
6.0	.9	X	O	*
5.6	1.7	.9	O	*
5.2	2.5	1.7	.9	O
4.8	3.1	2.5	1.7	.9
4.4	3.5	3.1	2.5	1.7
4.0	3.8	3.5	3.1	2.5

SOIL TYPE III
Crop group

	A	B	C	D
7.2	O	*	#	#
6.8	O	O	#	#
6.4	X	O	*	#
6.0	1.2	X	O	*
5.6	2.4	1.2	O	*
5.2	3.5	2.4	1.2	O
4.8	4.4	3.5	2.4	1.2
4.4	5.0	4.4	3.5	2.4
4.0	5.4	5.0	4.4	3.5

SOIL TYPE IV
Crop group

	A	B	C	D
7.2	O	*	#	#
6.8	O	O	#	#
6.4	X	O	*	#
6.0	1.7	X	O	*
5.6	3.3	1.7	O	*
5.2	4.7	3.3	1.7	O
4.8	5.8	4.7	3.3	1.7
4.4	6.5	5.8	4.7	3.3
4.0	7.0	6.5	5.8	4.7

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.

Nitrate and Ammonia Nitrogen Tests

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 ammonium compounds. Thus organic nitrogenous fertilizer materials and leguminous crop residues are more readily attacked, due to their high protein content. Some fertilizer materials, such as sulfate of ammonia and ammonium phosphates, add ammonium compounds directly to the soil.

Nitrogen in the form of ammonium compounds may be utilized as such by many plants, especially during their early growth period. Under normal field conditions this form of nitrogen is rapidly converted, first into nitrites, and then into nitrates, by certain species of bacteria. Hence soils rarely show high ammonia tests, unless they have been fertilized with nitrogen in this form during the past few weeks. At other times a high ammonia test is an indication of poor nitrificaton potentialities in the soil, as a consequence of high acidity, of poor soil aeration due to water-logging, or of some other abnormal factor.

Soils showing high ammonia tests cannot be reliably tested for potassium by the usual simple methods, due to interference of the ammonium ion in the chemical reaction.

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.

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 been 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.

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.

Recommendations as to Nitrogenous fertilization are thus based upon consideration of the following factors: nitrate and ammonia tests; applications of stable manure; crop residues; texture and organic content of the soil; and crop requirements.

For convenience in interpretation, it is desirable to assign arbitrary ratings with reference to the conditions of probable availability of nitrogen in the soil, as follow:

Very high: heavily manured (over 30 tons per acre) within past year; or very high nitrate or ammonia test.
High: moderately manured during past year; or heavily manured within recent years (not in past year); or dark colored clay loam soil above 5.6 pH; or high nitrate or ammonia test.

Medium high: leguminous green manure crop, clover or alfalfa sod plowed under; or dark colored loam soil above 5.6 pH; or medium high nitrate or ammonia test.
Medium: grass sod plowed under; or dark colored sandy loam soil above 5.6 pH; or medium or grayish brown loam or silt loam soil above 5.6 pH; or medium nitrate or ammonia test.
Low: medium or grayish brown sandy loam soil above 5.6 pH; or low nitrate or ammonia test.
Very low: all other cases, with very low nitrate or ammonia test.

On the basis of requirements with reference to nitrogenous fertilization, crops may be grouped as follows for average Connecticut conditions:

N-I	N-II	N-III	N-IV
Very high	*High*	*Medium*	*Low*
Asparagus	Beets, late	Barley	Alfalfa
Beets, early	Broccoli	Blue grass	Beans
Cabbage, early	Cabbage, late	Corn	Clovers
Cauliflower	Carrots	Parsnips	Rye
Celery	Cucumbers	Peas	Soybeans
Lettuce, early	Eggplant	Peppers	Vetch
Rhubarb	Lawn grasses	Pumpkins	
Spinach	Muskmelon	Rutabaga	
Tobacco*	Oats	Timothy	
	Onions	Turnips	
	Potatoes	Watermelon	
	Radishes		
	Squash		
	Tomatoes		

The following table is given as a suggestion, to be liberally interpreted in the light of the best judgment of the person making the recommendation:

NITROGEN FERTILIZATION TABLE

(In terms of pounds of nitrogen per acre to be supplied as a fertilizer)

	Nitrogen requirement group			
NITROGEN AVAILABILITY RATING	N-I	N-II	N-III	N-IV
Very high	60	20	0	0
High	80	40	0	0
Medium high	100	60	20	0
Medium	120	80	40	0
Low	140	100	60	20
Very low	160	120	80	40

Phosphorus

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.

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. Under such conditions Connecticut soils usually receive no lime, and a high acidity and low phosphorus availability are the rule on most areas of this type.

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 different degrees of phosphorus availability. 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 direct applications of arsenical materials may give high tests, regardless of their phosphorus content. Hence results in such cases are unreliable.

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.

Recommendations as to phosphorus fertilization are thus based on the following factors: Phosphorus tests; pH; aluminum tests; and crop requirements.

The various common field and vegetable crops may be grouped as follows with respect to their phosphorus requirements, for Connecticut conditions:

P-I	P-II	P-III	P-IV
Very high	*High*	*Medium*	*Low*
Asparagus	Alfalfa	Barley	Bent grasses
Beets	Broccoli	Beans	Buckwheat
Cabbage, early	Brussels sprouts	Blue grass	Fescues
Cauliflower	Cabbage, late	Clover, alsike	Oats
Celery	Carrots	Clover, red	Red top
Lettuce	Cucumbers	Clover, white	Rye
Potatoes	Eggplant	Corn	Sweet clover
Radishes	Muskmelons	Parsnips	Timothy
Rhubarb	Onions	Peas	
Spinach	Sweet potatoes	Peppers	
	Rutabagas	Pumpkins	
	Squash	Soybeans	
	Tobacco	Strawberries	
	Tomatoes	Vetch	
	Turnips	Watermelons	

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*Has special high nitrogen requirement, especially when the fertilizer supplies nitrogen chiefly in organic materials.

The following table is given as a suggestion, to be liberally interpreted on the basis of the best judgment of the person making the recommendation:

PHOSPHORUS FERTILIZATION TABLE

(In terms of pounds of P_2O_5 per acre to be supplied as a fertilizer)

	Phosphorus requirement group			
PHOSPHORUS AVAILABILITY	P-I	P-II	P-III	P-IV
Very high	100	60	20	0
High	120	80	40	0
Medium high	140	100	60	20
Medium	160	120	80	40
Low	180	140	100	60
Very low	200	160	120	80

Potassium

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. This may now be readily determined by the simple soil testing method used by this Station.

Active potassium may be removed from the soil more rapidly than replenished by natural processes. 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.

High potassium tests should be obtained on soils planted to vegetable crops, tobacco and potatoes. Potash fertilization cannot be omitted on such crops, at least for more than one or two seasons, even on soils showing very high potash tests, since the existing favorable conditions cannot long be maintained by natural soil processes.

Legumes and general farm crops, on soils in otherwise favorable degrees of fertility, may require little or no potash fertilization when occasional applications of manure are used, if medium or high soil tests are shown. Soils with low and very low tests usually respond to the addition of potash to the soil, either in the form of fertilizer or manure, for most crops and permanent grass sods.

Recommendations as to potassium fertilization are thus based on the following factors: Potassium test; time of testing in relation to cropping; previous potash fertilization; crop requirements.

The various common field and vegetable crops are grouped as follows, with respect to their potassium requirements, for Connecticut conditions:

K-I	K-II	K-III	K-IV
Very high	*High*	*Medium*	*Low*
Asparagus*	Alfalfa	Barley	Bent grasses
Beets, early	Beets, late	Beans	Blue grass
Broccoli	Brussels sprouts	Corn	Buckwheat
Cabbage, early	Cabbage, late	Clover, alsike	Fescues
Cauliflower	Carrots	Clover, red	Oats
Celery	Cucumbers	Oats	Red top
Lettuce	Eggplant	Pumpkins	Rye
Parsnips	Muskmelons	Rutabagas	Strawberries
Sweet potatoes	Onions	Soybeans	Sweet clover
Radishes	Peas	Turnips	Timothy
Spinach	Peppers	Vetch	
Tobacco	Potatoes	Watermelons	
	Squash		
	Tomatoes		

The following table is given as a suggestion, to be liberally interpreted on the basis of the best judgment of the person making the recommendation:

POTASSIUM FERTILIZATION TABLE

(In terms of pounds of K_2O per acre to be supplied as a fertilizer)

	Potassium requirement group			
AVAILABLE POTASSIUM IN SOIL	K-I	K-II	K-III	K-IV
Very high	80	40	0	0
High	100	60	20	0
Medium high	120	80	40	0
Medium	140	100	60	20
Low	160	120	80	40
Very low	180	140	100	60

Calcium

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

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*Extra high requirement.

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. Such is the case with tobacco and potatoes.

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.

Magnesium

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 limestone. On soils giving high calcium and very low magnesium tests, or pH values as high as desired for the crop, magnesium sulfate (Epsom salts) is to be preferred. Commercial fertilizers which supply magnesium in these forms are now available.

Aluminum

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 so serious, especially with grasses, corn, oats, potatoes, and tobacco. A low or negative test is desirable, except for distinctly acid-tolerant plants.

Manganese

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.

Iron

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.

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.

Other Tests

Occasionally soils which give poor crops contain unusual or harmful concentrations of other chemical constituents. Abnormally high tests for chlorine and sodium show the presence of injurious amounts of common salt. Very high sulfate tests, on soils of unusual acidity, indicate the presence of harmful amounts of sulfuric acid. The presence of more than traces of nitrite nitrogen is likewise injurious, and is occasionally encountered on poorly aerated soils. In all questionable cases these possibilities should be fully investigated.

An illustration of the use of the tests as a basis for recommendation: In order to show the mechanism of applying the tests to practical problems, the following example is presented:

Farmer Jones has a field of medium brown loam soil, in grass sod, without recent previous fertilization. He wishes to use one-half of the field for potatoes and the other half for alfalfa. Soil tests are as follows:

pH	5.2
Nitrate nitrogen	Very low
Ammonia nitrogen	Low
Phosphorus	Medium
Potassium	Low
Calcium	Medium
Magnesium	Very low
Aluminum	Medium
Manganese	Low

Liming recommendations:

Potatoes are in lime requirement group D.
Alfalfa is in lime requirement group A.
The soil group is III.

For Group D at 5.2 pH—no lime.
For Group A at 5.2 pH—3.5 tons per A. (of a dolomitic limestone on account of very low Magnesium test.)

Fertilizer recommendations:

Potatoes—	N-II, medium N. availability rating*	80 lbs. N.
	P-I, medium available P	160 lbs. P_2O_5
	K-II, low available K	120 lbs. K_2O

The fertilizer should thus supply 80 lbs. N., 160 lbs. P_2O_5 and 120 lbs. K_2O. This could be done with 2000 lbs. per acre of a 4-8-6 fertilizer. Since the soil is very low in magnesium, but not sufficiently acid to require lime, magnesium should be used in the form of magnesium salts, such as magnesium sulfate, at the rate of 30 to 50 lbs. of MgO per acre.

Alfalfa—	N-IV, medium N. availability rating	No N.
	P-II, medium available P	120 lbs. P_2O_5
	K-II, low available K	120 lbs. K_2O

The fertilizer should thus supply 120 lbs. P_2O_5 and 120 lbs. of K_2O. This could be done with 1200 lbs. per acre of a 0-10-10 fertilizer; or by using 750 lbs. of 16 percent superphosphate and 240 lbs. of 50 percent muriate of potash.

Interpretations in Other Soil and Crop Regions

The tests given in this bulletin should give helpful information under all conditions. But it is quite probable that the interpretations will only partially apply to conditions of widely different soils and cropping systems. They will apply best to those obtaining in the northeastern United States. It is hoped that they will be thoroughly tried out in other sections, in comparison with other soil testing methods, under conditions that will form an adequate basis of interpretation with reference to soil and crop conditions to be encountered.

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*Given this rating because of grass sod plowed under.

Other Factors Affecting Crop Growth

Soil testing to determine the nutrient conditions within the soil by means of comparatively simple tests is a relatively new phase of soil science, and has been made possible by the rapid developments in our chemical knowledge during the present century. It promises to be a valuable contribution to the more intelligent management of the soil, helping to forestall crop failure due to improper fertilization and preventing wasteful use of unnecessary fertilizer ingredients.

However, the best fertilizer and liming practices cannot overcome the injurious effects of deficient or excessive moisture conditions, poor soil tilth, weed competition, improper cultural methods, or insect and plant disease troubles. All these factors must be reasonably favorable to plant growth, else the most thoughtful care in providing favorable nutrient conditions will come to naught.

PLANT TESTS

Using the Universal Soil Extracting Solution

It is frequently desirable to verify a case of suspected crop deficiency or nutrient abnormality by means of chemical examination of the plant itself. The visible symptoms produced by the serious deficiency or excess of a given constituent are frequently recognizable by the trained observer, if not modified by the effects of some other factor. But in the field, the plant may be suffering from maladjustment of two or more chemical constituents. Under such conditions, chemical tests of plant tissue are an aid to proper diagnosis.

For plant tissue tests of this sort, the material should be taken from the leaf petiole or from the succulent part of the stem in the portion of the plant most affected by abnormal symptoms. Normal and questionable plants both should be tested simultaneously wherever possible.

Suggested procedure for plant tests: Cut up a quantity of the plant tissue to be tested into small cubical sections about 2 mm. in thickness. Mix carefully, and measure a level half-teaspoonful of this material into the filter cone. Extract with 10 ml. of the Universal soil extracting solution and conduct the desired tests in the same manner as previously described for soils.

It is to be noted that the "special manganese test" must be used for plant material. It is usually desirable to test for the following constituents: nitrates, ammonia, phosphorus, potassium, calcium, magnesium, manganese and iron.

The color charts should be used for comparative purposes only, as the tests obtained vary widely with the chemical characteristics of the plant. Interpretations of the significance of estimated relative amounts should be based on comparison between normal and affected plants of the species in question.

Since the author has not made a thorough study of the application of plant tissue tests under various conditions, the reader is referred to the recent work of Thornton[1] and Carolus[2] along this line.

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[1] Circ. 204, Ind. Agr. Exp. Sta.
[2] Mimeographed publication, Va. Truck Exp. Sta., 1936.

APPLICATION OF TESTS TO DRAINAGE WATER FROM SOILS

It is frequently desirable to obtain a rough picture of the relative amounts of various soluble chemical constituents in the drainage water from soils, or in the waters of springs or streams. The tests previously described can be applied for this purpose, although a few adjustments are required to compensate for the poor buffer action of such dilute solutions. The following procedures are suggested for the various tests.

Nitrate nitrogen: Proceed as for soil test. Readings, in parts per million, corresponding to the chart colors are approximately as follows, from top to bottom: 20–12–8–5–2.5–0.8. If necessary, dilute with distilled water to a definite ratio before testing, and calculate results on basis of dilution used.

Ammonia nitrogen: Proceed as for soil test, except that only one drop of the reagent is added. Readings, in parts per million, corresponding to the chart colors are approximately as follows, from top to bottom: 40–20–10–5–2–1.

Phosphorus: Place in the spot plate depression 5 drops of the water to be tested. Add 5 drops of the Universal soil extracting solution. Proceed as for soil test, except that only one drop of reagent "B" is desirable. Readings, in parts per million, corresponding to the chart colors are approximately as follows, from top to bottom: 3–2–1–0.5–0.25–0.125

Potassium: Proceed as for soil test. Readings, in parts per million, corresponding to the chart lines are approximately as follows, from top to bottom: 60–50–40–30–20–15.

Calcium: Place in the test vial (10 by 50 mm.) 10 drops of the water to be tested. Add two drops of the Universal soil extract and one drop of the calcium reagent. Proceed as for soil test. Readings, in parts per million, corresponding to the chart discs are approximately as follows, from top to bottom: 400–300–200–100–75–50.

Magnesium: Place in the spot plate depression 10 drops of the water to be tested. Add five drops of the Universal soil extracting solution. Add one drop of Reagent A-2 and two drops of Reagent B. Proceed as for soil test. Readings, in parts per million, corresponding to the chart colors are approximately as follows, from top to bottom: 40–20–10–5–3–2.

Aluminum: Place in the spot plate depression four drops of water to be tested. Add one drop of Universal soil extracting solution, and one drop of the reagent. Proceed as for soil test. Readings, in parts per million, corresponding to the chart colors are approximately as follows, from top to bottom: 10–5–2–1–0.4–0.2.

Manganese: Place in the spot plate depression 10 drops of water to be tested. Add one drop of 1:3 acetic acid (one part glacial acetic acid to three parts of distilled water). Add one drop of reagent A and one drop of reagent B. Proceed as for soil test. Readings, in parts per million, corresponding to chart colors are approximately as follows, from top to bottom: 12–7.5–5–2.5–1–0.5.

Iron tests: Proceed as for soil tests. Readings, in parts per million, corresponding to color descriptions indicated, are approximately as follows: 50–25–10–5–2.5–1.0.

Sulfate sulfur: Proceed as for soil tests. Readings, in parts per million, made on the calcium chart, are approximately as follows, from top to bottom: 200–150–100–50–20–10.

Nitrite nitrogen: Proceed as for soil tests. Readings, in parts per million, corresponding to color descriptions, are approximately as follows: 10–5–2.5–1.0–0.5.

Sodium: Proceed as for soil test. Readings, in parts per million, made on the potassium chart are approximately as follows, from top to bottom: 600–500–400–300–200–150.

Chlorine: Proceed as for soil test. Readings, in parts per million, made on the calcium chart, are approximately as follows: 800–500–300–100–50–25.

Boron: Proceed as for soil test. Standardize readings against aqueous solutions of boron, as boric acid, of known concentrations, ranging from 50 to 2 parts per million.

Zinc: Proceed as for soil test. Standardize readings against aqueous solutions of zinc, as zinc chloride, of known concentrations, ranging from 50 to 5 parts per million.

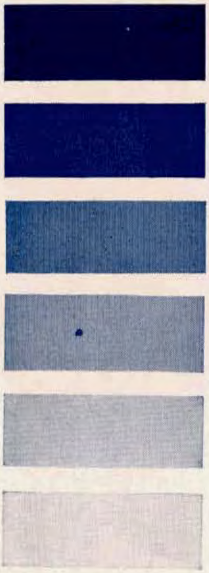
Copper: Place in the spot plate depression 10 drops of the water to be tested. Add two drops of Universal soil extracting solution, and proceed as for soil test. Standardize readings against aqueous solutions of copper, as copper sulfate, of known concentrations, ranging from 25 to 2 parts per million.

PLATE 1

NITRATE NITROGEN COLOR CHART

Universal Soil Testing System

Relative Reading	Approximate Pounds per Acre* (7″ Depth of Soil)
Very high	100
High	60
Medium high	40
Medium	20
Low	10
Very low	2



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*Test made on one drop of the undiluted soil extract. If diluted before testing, multiply by appropriate factor.

AMMONIA NITROGEN COLOR CHART

Universal Soil Testing System

RELATIVE READING	APPROXIMATE POUNDS PER ACRE* (7″ DEPTH OF SOIL)	
Extra high	400	🟧
Very high	200	🟧
High	100	🟧
Medium high	50	🟧
Medium	20	🟨
Low	10	🟨

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*Test made on four drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

PLATE 3

PHOSPHORUS COLOR CHART

Universal Soil Testing System

RELATIVE READING	APPROXIMATE POUNDS PER ACRE* (7″ DEPTH OF SOIL)	
Very high	300	
High	200	
Medium high	100	
Medium	50	
Low	25	
Very low	10	

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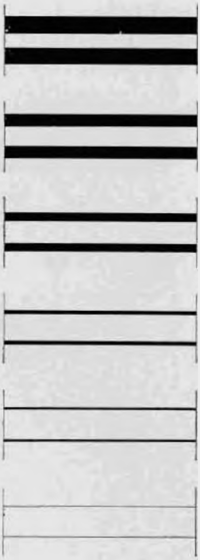
*Test made on ten drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

POTASSIUM COLOR CHART

Universal Soil Testing System

RELATIVE READING	APPROXIMATE POUNDS PER ACRE* (7″ DEPTH OF SOIL)
Extra high	600
Very high	500
High	400
Medium high	300
Medium	200
Low	150



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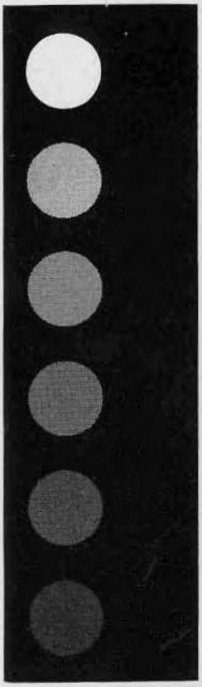
*Test made on ten drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

PLATE 5

CALCIUM COLOR CHART

Universal Soil Testing System

Relative Reading	Approximate Pounds per Acre* (7″ Depth of Soil)
Very high	4000
High	3000
Medium high	2000
Medium	1000
Low	750
Very low	500



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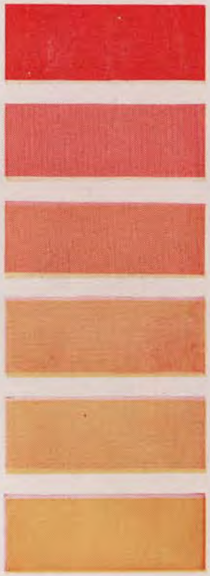
*Test made on ten drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

PLATE 6

MAGNESIUM COLOR CHART

Universal Soil Testing System

Relative Reading	(using Reagent A-2 (Titan yellow)) Approximate Pounds per Acre* (7" Depth of Soil)	
High	250	🟥
Medium high	100	🟥
Medium	50	🟥
Low	25	🟧
Very low	15	🟧
Extra low	10	🟧



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*Test made on ten drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.

PLATE 7

ALUMINUM COLOR CHART

Universal Soil Testing System

Relative Reading	Approximate Pounds per Acre* (7″ Depth of Soil)	
Very high	500	🟪
High	250	🟪
Medium high	100	🟫
Medium	50	🟧
Low	20	🟧
Very low	10	🟨

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*Test made on two drops of soil extract, diluted with two drops of Universal soil extracting solution. For other dilutions, use appropriate factor.

PLATE 8

MANGANESE COLOR CHART

Universal Soil Testing System

Relative Reading	Approximate Pounds per Acre* (7″ Depth of Soil)	
Very high	120	
High	75	
Medium high	50	
Medium	25	
Low	10	
Very low	5	

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*Test made on ten drops of undiluted soil extract. If diluted before testing, multiply by appropriate factor.