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Rapid Soil Tests for Estimating the Fertility Needs of Missouri Soils

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FOREWORD

The National attention has recently been focused on our soil. The danger of its depletion through erosion and exhaustion of its plant nutrient content by intensive cropping is appreciated. The fuller appreciation not only of the soil's stock of plant nutrients but also of the soil's activity in providing these in usable form has inspired attempts at rapid chemical tests of the soil's constituents. It has been the hope that differences so found may indicate the soil's productivity and thus aid in the better classification of land for agricultural use.

As various rapid tests have been developed, the College of Agriculture has experimented with them and certain of the more promising ones, such as the Modified Comber test for soil acidity and the Bray test for soluble phosphate, have been suggested for trial by county agents. However, as time has gone on the limitations of these tests for Missouri soils have become apparent.

The study reported herein is an attempt to improve on the methods in use for evaluating the levels of fertility of Missouri soils and in locating those to which specific treatments may be made. It seems evident from this and similar work in other states, that if the farmer is to be given proper assistance, the interpretation of tests of his soil is of great importance. As a consequence, a central laboratory where most of such tests may be made should support the extension workers in the field. Both the research workers in the laboratory and the extension men in the field may well cooperate in this diagnostic endeavor.

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Rapid Soil Tests For Estimating The Fertility Needs Of Missouri Soils.

L. D. BAVER and F. H. BRUNER*

Rapid chemical tests for estimating the available plant nutrients in soils are now being used rather extensively. Although considerable progress has been made in developing methods that are analytically feasible, some confusion still remains regarding the interpretations of the results obtained in terms of fertility needs and fertilizer recommendations.

It is the purpose of this bulletin, first, to report certain experimental results that have been obtained in studying the chemistry of rapid tests in the hope that they may contribute to further progress in the perfection of more satisfactory methods, and, second, to discuss the applicability of these results to the problem of diagnosing the fertility needs of Missouri soils.

It was not the object of these studies to investigate all of the various tests that are now available. A comparison of a number of these methods may be found in the work of Anderson and Noble (1).† On the other hand, it was hoped that a study of several methods, which varied considerably in the strength of the extracting solution, and thus in their ability to remove readily soluble nutrients from the major Missouri soil types, would provide results that could be used in formulating a more satisfactory method of soil testing under Missouri conditions. Moreover, it was felt that many of the existing chemical methods had not been thoroughly investigated from the standpoint of their analytical weaknesses. Consequently, efforts were made to determine the analytical accuracy of a given test in the presence of the different ions found in the ordinary soil extract.

One of the most difficult phases of any chemical method for determining readily soluble plant nutrients is the calibration of the extracted amounts of a given nutrient in terms of the quantity available to the plant. Inasmuch as recent experimental findings have shown rather close correlations between exchangeable cations and plant growth, the amounts of calcium, magnesium, potassium and manganese readily soluble in certain extracting reagents were

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†Numerals refer to "Literature Cited," page 16.

correlated with the amounts of these cations on the exchange complex. The quantities of exchangeable cations on the various Missouri soils were determined by accepted analytical procedures. Soluble phosphorus was determined according to the laboratory method of Truog (8).

METHODS OF MAKING RAPID SOIL TESTS

Lime Requirement

In the humid region a soil is neutral when the exchange complex is saturated primarily with calcium ions. A soil is acid when part of the exchangeable bases, (chiefly calcium) have been replaced by hydrogen ions. Theoretically, therefore, the best criterion for estimating the acidity and lime needs of the soil would be based upon the relative amounts of exchangeable hydrogen and calcium present. The exchangeable hydrogen would be a measure of the potential acidity and the exchangeable calcium a measure of available calcium. Moreover, soils with the same potential acidity, but with widely different contents of available calcium should not be expected to have the same lime requirement in order to grow a given legume.

If one knew the titration curve for every group of soils with the same clay and organic matter contents, one could estimate the lime requirement from the pH value and the amount of available calcium present. The pH value, without knowledge of clay and organic matter contents, would be inadequate since experimental results have definitely indicated that in most soils with pH values above 4.5 to 5.0 the hydrogen ion concentration, as expressed in terms of pH, is of secondary importance to the amount of available bases present. The pH value for a given soil is of significance only as it is an indication of its degree of saturation by bases. Total available bases depend both on the degree of saturation and on the amount of colloid in the soil.

Laboratory experiments on a large number of Missouri soils have shown that the modified Comber test for potential soil acidity is directly proportional to the exchangeable hydrogen present. Consequently, a combination of the Comber, or the potassium thiocyanate, and readily soluble calcium tests was used for estimating the lime requirements as given in Table 1. Such a combination helped to clarify many of the problems that had been previously encountered with many Missouri soils when either the pH or the soluble calcium test alone was used for determining the lime needs.

TABLE 1.—LIME REQUIREMENTS OF SOILS BASED UPON SOLUBLE CALCIUM AND COMBER TEST

Degree of Acidity by Comber	Amounts of Soluble Calcium	Pounds of Limestone Per Acre		
		Alfalfa Sweet Clover	Red Clover	Soybeans Lespedeza Alsike Clover
Very slight	Low	3000	2000	0
	Medium	2000	(1)	0
	High	(1)	0	0
Slight	Low	4000	2000	0
	Medium	3000	2000	0
	High	(1)	0	0
Medium—	Low	5000	3000	2000
	Medium	4000	2000	0
	High	2000	(1)	0
Strong	Low	6000	4000	3000
	Medium	5000	3000	1000
	High	4000	2000	0
Very strong	Low	8000	6000	4000
	Medium	7000	5000	2000
	High	6000	4000	(1)

(1) Will probably not require liming for success.

The Extracting Solution for Soluble Nutrients

There has been considerable variation in the method of extracting the readily soluble nutrients from a soil. The variations are associated with the acidity of the extracting solution as well as with the type of extractant for the different nutrients. A discussion of differences that may be expected in various soils as a result of the acidity of the extracting solution has been presented by Morgan (6). It is important to note that Morgan finds a weakly acidic extracting solution most suitable for the coarse-textured soils of Connecticut, while Truog (8) uses a sulfuric acid solution buffered at pH 3 to remove the readily soluble phosphorus from Wisconsin soils.

Many other examples could be cited to show the variations in opinion concerning the merits of a given acidity of the extracting solution. These examples, however, suggest in the first place that major soil differences are probably responsible for many of the apparently conflicting results between various methods, and, in the second place, that soil tests should be calibrated for a given soil region or state. Moreover, there is sufficient evidence to show that the technique of sampling to obtain a representative sample is often faulty (5). Differences in chemical tests may be due to individual soil variations either as a result of an insufficient number of samples from a given field or because of seasonal changes in the amount of nutrients in the soil.

Preliminary studies showed that the acidity of the Morgan extractant was too weak for the highly buffered silt loams and clays of Missouri. On the other hand, the Truog and Thornton (7) extractants removed nutrients in amounts similar to those obtained in base exchange studies and were more in agreement with field observations.

It was believed that one extractant for all of the nutrients would be distinctly advantageous from the standpoint of routine analyses in a service laboratory. One extractant would simplify the procedure, particularly if the rapid tests are to be made away from the laboratory. Consequently, 0.3N HCl was used to extract all readily soluble nutrients and 7 cc were used to approximately 3.5 grams of air-dried soil. This combination was shaken in a stoppered tube for a few minutes; and was then filtered to give a clear solution in which the contents of the different cations and anions were determined by the methods as given.

Readily Soluble Calcium

Ten drops of a sodium oxalate-sodium acetate solution (2 gms $Na_2C_2O_4$ plus 3 gms. CH_3COONa dissolved in 100 cc of H_2O and then added to 100 cc of glycerol) are added to 3 drops of soil extract, followed by the addition of 3.3 cc of water. The turbidity of the milky suspension is read against the same lines used in the potassium test. The following comments are necessary:

1. Glycerol increases the viscosity of the solution so that the precipitate will not settle out too rapidly for turbimetric readings. Keeping the precipitate in suspension permits more accurate readings than are possible by any reading method allowing it to settle on the bottom of the tube. The tube should be shaken before and after adding the distilled water and prior to making the readings.
2. The sodium acetate buffers the solution at about pH 6. The precipitate is insoluble at this reaction, but will dissolve below pH 4.
3. Magnesium is not precipitated.

Readily Soluble Phosphorus

Three drops of a standard ammonium molybdate solution (2.5 gms in 10N H_2SO_4) are added to four drops of soil extract followed by 3.8 cc of distilled water. The blue color is developed with powdered stannous oxalate. The following precautions should be kept in mind:

1. The blue color usually becomes more intense with time. Readings should be made about one minute after the addition of stannous oxalate.
2. The presence of arsenic compounds causes the development of a blue color, even in the absence of soluble phosphates.
3. If the ammonium molybdate is placed in the extracting solution (which is the case with many tests) the results may often be influenced by the presence of organic matter, as well as by iron-manganese concretions. Soluble organic matter hinders the development of the blue color. Iron-manganese concretions intensify the color. The addition of the molybdate to the filtered extract obviates these difficulties.

Readily Soluble Potassium

Ten drops of a sodium nitrite solution (25 gms $NaNO_2$ dissolved in 40% formaldehyde to make 100 cc) and one drop of a cobaltous nitrate solution (5 gms $Co(NO_3)_2 \cdot 6 H_2O$ plus 1 cc glacial acetic acid dissolved in distilled water to make 10 cc) are shaken together in a standard tube to form sodium cobalti-nitrite. Seven drops of soil extract are added and the potassium precipitated by adding 3.2 cc of an alcoholic sodium acetate solution (3 gms CH_3COONa in 100 cc 95% ethyl alcohol). The density of the golden yellow, fine-grained precipitate is read against a background of lines of varying widths and degrees of darkness. The following comments are necessary:

1. The formaldehyde removes the ammonium ions from solution by forming the hexamethylamine.
2. The sodium nitrate and cobaltous nitrate are not mixed until just prior to making each test because (a) neither single solution deteriorates with age, and (b) the previously combined solutions not only deteriorate with age, but also give precipitates which rapidly increase in density with time.
3. The use of powdered sodium cobalti-nitrate requires more sensitive precautionary measures in mixing than does the employment of two solutions. Moreover, a more uniform color is obtained with a solution because of more accurate measurements.
4. Ethyl alcohol produces as good results as the more expensive isopropyl. Sodium acetate buffers the alcohol so that the precipitation of potassium takes place at approximately the same pH.
5. The particle size of the precipitate depends upon the speed of mixing so that consequently the turbidity or smaller size of the particles in suspension is guaranteed by the instantaneous and complete mixing of the alcohol with the contents of the tube.
6. The reagents are nearly saturated solutions at ordinary room temperatures. If kept in a cold place, they should be warmed prior to using so that all of the solid material goes into solution.
7. If the temperature of the solutions and extract is higher than 80° to 85° F. the precipitate does not form completely and low results are obtained. All reagents, including the extract should be cooled prior to making the test.

Readily Soluble Magnesium

Five drops of a titan yellow solution (0.15 gm titan yellow plus 0.1 gm NaH_2PO_3 in 100 cc of 50% methyl alcohol) are added to 4 drops of soil extract. Then 3.3 cc of basic sucrose solution (83.3 gm NaOH plus 50 gm sucrose per liter of solution) are added. A yellow to red suspension, depending upon the amount of magnesium present, is formed. The colored suspension is compared with tubes containing standard amounts of magnesium given the same treatments. The following comments are significant.

1. Even though the precipitate settles out, the color is stable and the suspension need only be shaken before making the readings.
2. The test depends upon a dye adsorption on the insoluble precipitate of magnesium hydroxide. The use of the spot plate in which rather

high concentrations of materials are used to produce a red lake makes it difficult to distinguish color variations. By lowering the concentration of magnesium, a fine-grained precipitate is formed which gives a colored suspension that is easily read.

3. Precipitates of aluminum and calcium hydroxides also cause the formation of color lakes. Since aluminum and calcium are present in most soil extracts, the alkalinity was raised to keep aluminum in solution; sucrose prevents the precipitation of calcium. The color intensity is slightly lower, but since most extracts contain more calcium and aluminum than magnesium, the slight change in color intensity is much less serious than the disturbances due to other precipitates.
4. The presence of the phosphate ion intensifies the red color, even in the presence of small amounts of magnesium. Since the concentration of the phosphate ion varies in soil extracts, an excess of phosphate ions in the reagent nullifies any effects of this ion in the extract.

Readily Soluble Manganese

In this test 1.8 cc of 1:1 nitric acid are added to 5 drops of soil extract in a small, flat-bottom tube (16 x 90 mm). One small spoonful (about 0.07 gm) of solid sodium bismuthate is then added. After shaking and allowing the excess bismuthate to settle out, a red to purple color is formed which is read against tubes containing standard amounts of manganese carried through the same procedure. The following comments are necessary:

1. The usual benzidine reaction for the presence of manganese takes place entirely too rapidly for accurate readings.
2. Sodium bismuthate oxidizes manganese in the cold and produces a color which is stable over a period of 2 to 3 hours.
3. About 15 minutes are required for the complete settling of the excess bismuthate. The chloride from the extracting solution is oxidized to free chlorine and it is more satisfactory to wait until most of the bubbles have risen and disappeared. In the majority of the cases the settling of the bismuthate and the final escape of chlorine occur in the same length of time.

Readily Soluble Aluminum

One drop of soil extract, 4 cc of water, 5 drops of a sodium acetate buffer (8.16 gm $CH_3COONa, 3H_2O$ plus 10 cc glacial acetic acid plus 90 cc of H_2O), one drop of a sodium sulfide solution (5 gm $Na_2S.9H_2O$ in 100 cc H_2O), and 5 drops of an aluminon solution (0.1 gm aurin tricarboxylic acid in 100 cc H_2O containing one drop of concentrated NH_4OH) are shaken together. The intensity of the red color is compared with tubes containing known amounts of aluminum similarly treated. The following comments are necessary:

1. The test depends upon dye adsorption on colloidal aluminum hydroxide. The sodium acetate buffer lowers the pH to favor the formation of colloidal alumina.
2. Ammonium hydroxide forms the ammonium salt of aluminum.
3. Ferric iron produces a violet coloration with this reagent. The hydrogen sulfide formed from sodium sulfide reduces the iron to the ferrous state and removes its influence in the color formation.

TRIALS OF RAPID TESTS ON MISSOURI SOILS

Standardization of Rapid Tests

Tests were made of 58 Missouri soils, involving 14 different soil series, in order to compare the rapid tests with more detailed laboratory soil analyses. A part of these results are given in Table 2. The exchangeable calcium, magnesium and potassium were determined in extracts obtained from the soil by a modification of the Kappen method (4). The readily soluble phosphorus was measured by the laboratory method of Truog (extraction at pH 3 in 0.001N H_2SO_4). The approximate pounds per acre equivalent for the various rapid test designations are given in Table 3. The original intentions contemplated five classifications, very low, low, medium, high and very high. Analysis of the data, however, indicated that it was difficult to obtain satisfactory differentiations between very low and low amounts. It is doubtful if more than three groupings, namely, low, medium and high, are justified.

It is essential to note the agreement between determinations by the regular laboratory methods and by the rapid tests. In the case of calcium, where relatively large amounts are involved, it is possible to compare these actual amounts as obtained by both techniques. For example, a 10% variation in 3000 pounds would be only 300 pounds. This amount is considerably less than the 2000 pounds used as the differential between the different groups. On this basis, 70% of the samples agreed within 10%, 90% within 20% and 96% within 30%. If the agreement is determined according to placement within the correct group, then 90% fall within the same group and 10% fall within classes adjacent to each other.

Comparisons of the results for magnesium show that 87% of the samples are placed into the same group and 13% into adjacent groups by the two methods.

The phosphorus determinations show that the two methods placed 80% of the samples into the same group, 12% into adjacent groups and 8% into classes that are widely different.

The potassium results are not so satisfactory. Only 58% of the samples are placed within the same group; 31% fall into adjacent groups and 11% into classes that are widely different. The potash test, even in the hands of an experienced analyst, does not attain a reliability comparable to that of the others.

TABLE 2.—RESULTS OBTAINED WITH RAPID TESTS ON SEVERAL MISSOURI SOILS

Soil Type	Lime Requirements lbs./A (Sweet Clover)	Calcium Exchange-able lbs./A	Calcium Rapid Test	Magnesium Exchange-able lbs./A	Magnesium Rapid Test	Potassium Exchange-able lbs./A	Potassium Rapid Test	Phosphorous Laboratory lbs./A	Phosphorous Rapid Test	Manganese Rapid Test M.E./100 gm.	Aluminium Rapid Test M.E./100 gm.
Clarksville gravelly loam	4000	468	L*	96	L	267	M	21	L	0.16	5
Clarksville gravelly loam	6000	1248	L	113	L	304	M	22	L	0.30	7
Grundy silt loam	5000	5120	H	183	M	120	M	48	L	0.35	6
Grundy silt loam	1000	6680	H	170	M	470	M	84	L	0.48	6
Huntington silt loam	1000	5400	H	185	M	190	M	200	VH	0.50	6
Huntington silt loam	2000	3840	M	137	L	105	M	40	L	0.32	6
Knox silt loam	2000	5320	H	173	M	425	H	200	VH	0.40	6
Knox silt loam	2000	4620	H	142	M	270	H	58	M	0.35	5
Lebanon silt loam	3000	2440	L	146	M	245	M	Tr	Tr	0.32	5
Marshall silt loam	1000	5760	H	391	H	390	H	34	L	0.48	7
Marshall silt loam	3000	6000	H	362	H	819	H	139	H	0.15	6
Memphis silt loam	3000	3468	M	122	L	325	M	15	Tr	0.75	7
Memphis silt loam	5000	1640	L	130	L	230	M	41	L	1.30	8
Putnam silt loam	6000	2600	M	146	M	255	M	45	L	0.48	6
Sarpy very fine sandy loam	0	23560	VH	3360	VH	70	VL	Tr	VL	0.32	0
Sarpy silty clay loam	1000	7640	VH	406	H	80	L	260	VH	0.40	4
Sarpy clay	2000	10240	VH	480	VH	395	VH	276	VH	0.40	4
Sharkey clay	2000	7960	VH	307	H	200	VH	118	H	0.70	4
Sharkey clay	0	11240	VH	826	VH	590	VH	200	VH	0.48	3
Shelby loam	4000	4392	H	137	M	240	M	30	L	0.32	6
Shelby loam	2000	3600	M	142	M	380	H	61	M	0.25	4
Summit silt loam	5000	5400	H	183	M	195	M	36	L	0.16	8
Summit silt loam	4000	4840	H	216	M	100	L	39	L	0.25	8
Union silt loam	5000	1860	L	242	M	50	L	Tr	Tr	0.65	6
Union silt loam	1000	3620	M	262	M	175	M	Tr	Tr	0.60	8
Wabash silt loam	6000	11200	VH+	427	H	520	VH	194	VH	0.50	5
Wabash clay	2000	13240	VH+	1776	H	80	M	270	VH	0.08	4

*VL=Very low
L=Low
M=Medium
H=High
VH=Very high

TABLE 3.—POUNDS PER ACRE EQUIVALENTS OF RAPID TEST VALUES

Readily Soluble Constituents	Pounds Per Acre Equivalent Low	Medium	High	Very High
Ca	<3000	5000	7000	>7000
Mg	<150	300	450	>450
K	<150	300	450	>450
P	<50	100	150	>150

Comparisons of Different Rapid Tests

A comparison was made of the results from soils within the state by the rapid soil tests as designed by different individuals. The results are reported in Table 4. A very good agreement was obtained in the phosphate tests between the Truog, Thornton, and Missouri techniques. The Bray test (2), however, gave less satisfactory results. The agreement between the different methods in the potassium tests was not as satisfactory as one should desire. Undoubtedly, the difficulty of making reliable potassium determinations accounts for these variations. Perhaps, if a specific extractant had been used for potassium, more reliable results would have been secured.

Chemical Reliability of Rapid Soil Tests

On the basis of the experience gained in attempting to develop a rapid soil test that would be analytically satisfactory, both from the standpoint of the chemistry of the test and the technique of making the determinations, the following conclusions have been reached.

1. A universal extractant may be expected to give less reliable results than a specific extractant for the nutrient in question.
2. Many of the tests that are now being used are not entirely specific for the given nutrient, but may be influenced by other ions found in the soil extract.
3. No rapid chemical test can be expected to be uniformly applicable to all soils and soil conditions. The techniques should be standardized or different tests employed for different soil areas or regions.
4. The technique of sampling is very important and should be standardized so as to insure satisfactory results. A considerable number of spadings per field should be taken to give a representative sample and at the time of the year which will minimize the seasonal differences.
5. From the evidence at hand it would seem that the most reliable testing within a state will usually be done in the laboratories of the College of Agriculture, although some of the simpler tests may be done in the field.
6. The value of the tests to the farmer will be dependent on the proper interpretation of the data secured. Such interpretations can be made only when some knowledge of the many characteristics of the soil is available.

TABLE 4.—A COMPARISON OF VARIOUS METHODS FOR DETERMINING SOLUBLE PHOSPHORUS AND POTASSIUM

Soil Type	Phosphorus					Potassium			
	Laboratory	Rapid Tests				Laboratory	Rapid Tests		
	lbs./Acre	Truog	Thornton	Bray	Missouri	lbs./Acre	Truog	Thornton	Missouri
Sarpy silty clay loam	260	VH*	VH	L	VH	80	H	VH	H
Sarpy very fine sandy loam	Tr	VH	VH	L	VH	70	H	VH	VH
Sarpy clay	276	VH	VH	L	VH	395	M	VH	VH
Sarpy clay	418	VH	VH	L	VH	608	H	VH	VH
Sarpy loam	20	VH	VH	H	VH	507	M	VH	H
Sharkey clay	130	H	H	VL	H	109	M	H	M
Sharkey clay	200	H	VH	VL	VH	590	M	VH	VH
Sharkey clay	118	H	VH	VL	H	200	H	VH	VH
Shelby loam	61	L	M	H	M	380	H	VH	H
Shelby loam	Tr	VL	VL	VL	L	260	M	L	M
Shelby loam	30	VL	L	L	L	240	H	H	M
Grundy silt loam	56	VL	L	VL	L	216	M	VL	M
Grundy silt loam	27	VL	VL	VL	L	187	L	VL	M
Grundy silt loam	84	VL	L	L	L	470	M	VH	M
Grundy silt loam	55	VL	L	L	L	320	H	VH	M
Grundy silt loam	48	VL	VL	VL	L	120	L	VL	M
Grundy silt loam	96	L	L	L	H	109	M	L	L
Knox silt loam	200	VH	VH	L	VH	425	H	VH	H
Knox silt loam	247	VH	VH	H	VH	671	VH	VH	VH
Knox silt loam	99	M	H	M	M	211	M	VH	H
Knox silt loam	Tr	VL	VL	L	Tr	133	L	VL	L
Knox silt loam	48	VL	L	M	L	156	M	VL	H
Knox silt loam	58	L	M	L	M	270	M	H	H
Marshall silt loam	31	VL	VL	L	L	168	L	VL	M
Marshall silt loam	102	H	H	L	L	296	VH	VH	H
Marshall silt loam	139	VH	VH	L	H	819	VH	VH	H
Marshall silt loam	34	VL	VL	H	L	390	H	VH	H
Memphis silt loam	41	VL	L	H	L	230	M	VL	M
Memphis silt loam	15	VL	VL	VL	Tr	325	M	H	M
Summit silt loam	39	VL	VL	VL	L	100	M	VL	L
Summit silt loam	43	VL	L	VL	L	148	H	H	M
Summit silt loam	36	VL	VL	VL	L	195	M	L	M
Summit silt loam	39	VL	L	VL	L	273	M	M	H

*VL=Very low
L=Low
M=Medium
H=High
VH=Very high

RELATION OF RAPID SOIL TESTS TO THE FERTILITY OF MISSOURI SOILS

Agreement of Rapid Soil Tests With Response to Fertilizer Treatments

It is difficult to analyze accurately the response by Missouri soils to fertility treatments in light of the results obtained with rapid soil tests. In the first place, there is an insufficient number of field experiments involving enough soil types to permit conclusive data. In the second place, almost all of the major upland soils of Missouri, that have not been treated, will respond to lime and phosphorus. The rapid soil tests will usually show medium to high acidity and low phosphorus. The potassium status is somewhat different. Some soils contain large amounts of soluble potassium by the rapid tests and others possess small quantities. Some soils respond to potash fertilizers, others do not. Unfortunately, the correlation between the potassium test and the response to potash fertilizers is not very satisfactory. Seasonal influences may account for a part of this lack of correlation inasmuch as available potassium fluctuates markedly during the growing season.

If the results of the outlying experiment fields which were in operation from 1905 to 1923 are considered (3), one obtains the relationship between the response from potash fertilizers and soil tests as shown in Table 5. These tests were made either on samples of soil taken from the experimental fields in 1922 or on soil survey samples of the same soil types collected during the progress of the field surveys. It is noted that no close correlation exists between

TABLE 5.—RETURNS FROM POTASH FERTILIZATION IN RELATION TO READILY SOLUBLE POTASSIUM

Soil Type	Value of increase from potash fertilizer (Dollars)	Readily soluble potassium
Marshall silt loam	— 2.42	Medium
Grundy silt loam	+ 1.03	Medium†
Shelby loam	+ 6.91	Medium†
Putnam silt loam	— 0.42	Low
Oswego silt loam	— 1.12	Low
Eldon silt loam	+ 7.96	Medium†
Cherokee silt loam	+ 8.52	Medium†
Gerald silt loam	+ 8.88	Low
Bates loam	— 1.67	Low
Union silt loam	+ 1.28	Low
Lebanon silt loam (Strafford)	+ 1.11	Low
Lebanon silt loam (Cuba)	— 2.50	High
Clarksville gravelly loam	— 3.99	Medium

†Average value for all samples collected during soil survey. Other samples came from experimental field.

the value of increase from potash fertilizer and the amount of readily soluble potassium shown by the test. More information is needed under Missouri conditions before definite statements concerning the potassium test can be made.

Empirical Classification of Missouri Soil Types and Their Fertility Levels as Measured by Rapid Soil Tests

In order to obtain some picture of the possibility of using rapid chemical tests to characterize the fertility level of a given soil, the more important soil types of Missouri were analyzed for total nitrogen, soluble phosphorus, lime requirement (Comber), exchangeable calcium and potassium. About 400 samples that were collected during the soil survey field operations were used.

The various soils were divided into 5 classes, namely, A, B, C, D and E, on the basis of their decreasing general productivity as determined by field observations. The relationship of the aforementioned chemical determinations to the different productivity levels is given in Table 6. It is interesting to note that soluble phosphorus,

TABLE 6.—RELATIONSHIP OF CHEMICAL ANALYSES TO SOIL PRODUCTIVITY CLASSES

Soil Class	Number of Samples	Total Nitrogen lbs./A	Soluble Phosphorus lbs./A	Exchangeable Potassium M.E./100 gm.	Exchangeable Calcium M.E./100 gm.	Lime Requirement (Comber) lbs./A
A—Good	166	3172	116	0.38	18.6	1000
B—Above Medium	50	3366	60	0.42	13.9	2000
C—Medium	76	3117	54	0.31	10.1	3500
D—Below Medium	75	1893	27	0.27	5.8	4000
E—Poor	50	1930	25	0.31	5.4	4000

exchangeable calcium and Comber lime requirement tests show a rather definite relation to the productivity ratings of these Missouri soils, and the nitrogen content a less definite relationship. The similarity in the total nitrogen in Classes A, B and C is due to the fact that several of the flat prairie soils, which are placed in classes B and C because of acidity and poor physical properties, contain relatively large amounts of nitrogen. However, the nitrogen content of D and E soils is decidely lower than that of the other three classes. It will be observed that the results indicate a distinct uniformity in the amount of exchangeable potassium throughout all classes. These data suggest the need of more reliable potassium results.

GENERAL SUMMARY AND CONCLUSIONS

An attempt was made to develop and standardize rapid soil tests for Missouri soil conditions. The tests were studied from the viewpoint of their chemical accuracy as well as their ability to provide a reliable index of fertility needs. Although the technique that was developed gave more satisfactory results than other tests that were being used within the state, yet it is obvious that the problem of measuring soil fertility levels by chemical soil tests is not completely solved, and that further work is needed to give a more accurate diagnosis of the fertility requirements of the soils of Missouri.

The following conclusions seem justified as a result of these studies:

1. No rapid soil test is universally applicable to all soil or soil conditions. Each test should be carefully investigated in relation to the soils of a given state or region.
2. Rapid soil tests may give misleading results in the hands of those unqualified to interpret them.
3. A standardization of sampling technique is necessary to obtain representative samples of the soils in question.
4. It is doubtful if the results of any test can be reliably interpreted unless the different properties of the soil are well understood.
5. The most reliable interpretation of rapid soil tests will usually be made by those informed regarding the soils of the state and the techniques of the testing employed.
6. Soil testing in the field, with the exception of the simpler and better known methods, is subject to considerable uncertainty. This is particularly true of those used for making precise recommendations as to the kind and amount of fertilizer to apply.
7. From the standpoint of the techniques involved in rapid soil tests the following observations seem warranted:
   a. The tendency towards the use of a universal extractant for all nutrients is resulting in less reliable data than when a specific extractant for each nutrient is used. This is particularly true in those cases where a large number of nutrients are estimated from one extraction of the soil.
   b. Many of the rapid tests that are now being used are not specific enough for the nutrient in question. They may be affected by other ions in the soil extract.

8. The matter of rapid soil tests needs further study, particularly in connection with data from experiment field plots. Where the results of such studies are available, properly interpreted soil tests may be of great value in connection with fertility recommendations.
9. When rapid soil tests have been more completely developed for the different soil areas, their use on subsoil samples as well as samples of the surface soil, particularly in relation to the growth and treatment of deep rooted crops, should give information of value.

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