

RAPID TESTING OF SOILS FOR PLANT FOOD DEFICIENCIES

UNDER SOUTHERN CONDITIONS

BY

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TABLE OF CONTENTS

PREFACE - - - - - PAGE 1

INTRODUCTION - - - - - 2

REVIEW OF LITERATURE - - - - - 3

EXPERIMENTAL - - - - - 6

RESULTS AND DISCUSSION - - - - - 13

PLATES - - - - - 22

TABLES - - - - - 41

SUMMARY - - - - - 44

BIBLIOGRAPHY - - - - - 45

LIST OF PLATES

	PAGE
PLATE 1. OKTIBBEHA FINE SANDY LOAM COVERED WITH A VERY POOR SOD - - - - -	22
PLATE 2. OKTIBBEHA SANDY LOAM COVERED WITH A GOOD SOD - - - - -	23
PLATE 3. OKTIBBEHA FINE SANDY LOAM COVERED WITH HENBIT - - - - -	24
PLATE 4. OKTIBBEHA FINE SANDY LOAM COVERED WITH BUR CLOVER AND HAIRY VETCH-	25
PLATE 5. MYATT SANDY LOAM SHOWING A VERY POOR GROWTH OF COTTON - - - - -	26
PLATE 6. MYATT FINE SANDY LOAM SHOWING A MEDIUM GROWTH OF COTTON - - - - -	27
PLATE 7. OKTIBBEHA FINE SANDY LOAM SHOWING A POOR GROWTH OF COTTON - - - - -	28
PLATE 8. OKTIBBEHA FINE SANDY LOAM SHOWING A MEDIUM GROWTH OF COTTON - - - - -	29
PLATE 9. RUSTON VERY FINE SANDY LOAM COVERED WITH A VERY POOR GROWTH OF VETCH - - - - -	30
PLATE 10. RUSTON VERY FINE SANDY LOAM COVERED WITH A GOOD GROWTH OF VETCH -	31
PLATE 11. HOUSTON FINE SANDY LOAM COVERED WITH A POOR SOD - - - - -	32
PLATE 12. HOUSTON FINE SANDY LOAM COVERED WITH A GOOD SOD - - - - -	33
PLATE 13. HOUSTON FINE SANDY LOAM SHOWING A POOR GROWTH OF CORN - - - - -	34
PLATE 14. HOUSTON SANDY LOAM SHOWING A GOOD GROWTH OF CORN - - - - -	35
PLATE 15. KIRVIN VERY FINE SANDY LOAM SHOWING A VERY POOR GROWTH OF COTTON-	36
PLATE 16. KIRVIN VERY FINE SANDY LOAM COVERED WITH A MEDIUM GROWTH OF COTTON - - - - -	37
PLATE 17. LUFKIN SANDY LOAM SHOWING MEDIUM GROWTH OF COTTON - - - - -	38
PLATE 18. LUFKIN SANDY LOAM, 1st TWO INCHES UNDER FOREST COVER - - - - -	39
PLATE 19. RELATIVE GROWTH OF RYE PLANTS AS AFFECTED BY VARIATIONS OF POTASSIUM TREATMENT ON OCKLOCKNEE FINE SANDY LOAM - - - - -	40

LIST OF TABLES

	PAGE
TABLE I. A COMPARISON OF VEGETATIVE GROWTH AND THE AMOUNTS OF IONS EXTRACTED BY THE BUFFERED PERCHLORIC ACID SOLUTION ON SEVERAL IMPORTANT SOUTHERN SOILS - - - - -	-41
TABLE II. THE RESIDUAL EFFECT OF FERTILIZER TREATMENT UPON OCKLOCKNEE FINE SANDY LOAM FROM FERTILIZER RATES AND RATIOS TESTS UPON YIELDS OF RYE, EXCHANGEABLE POTASSIUM, AND RAPID TEST VALUES UNDER GREENHOUSE CONDITIONS - - - - -	42
TABLE III. THE INFLUENCE OF FERTILIZER TREATMENTS ON THE YIELDS OF SEED COTTON AND THE IONS REMOVED BY THE BUFFERED PERCHLORIC ACID SOLUTION ON A OCKLOCKNEE FINE SANDY LOAM SOIL - - - - -	42
TABLE IV. THE INFLUENCE OF FERTILIZER TREATMENT ON THE YIELDS OF SEED COTTON AND THE IONS REMOVED BY THE BUFFERED PERCHLORIC ACID SOLUTION ON A LUFKIN CLAY SOIL - - - - -	42
TABLE V. THE INFLUENCE OF FERTILIZER TREATMENTS ON THE YIELDS OF SEED COTTON AND THE IONS REMOVED BY THE BUFFERED PERCHLORIC ACID SOLUTION ON LINTONIA SILT LOAM - - - - -	43
TABLE VI. THE EFFECT OF FERTILIZER TREATMENTS UPON THE FORMS OF PHOSPHORUS IN OCKLOCKNEE FINE SANDY LOAM - - - - -	43
TABLE VII. THE EFFECT OF FERTILIZER TREATMENTS UPON THE FORMS OF PHOS- PHOROUS IN LUFKIN CLAY - - - - -	43

PREFACE

The work herein reported is not in a virgin field. Earlier investigators have made a very definite contribution to this study. The writer has exercised no hesitancy in using results of others when it appeared to serve a worthwhile purpose for the situation at hand. In view of this fact, the writer is deeply indebted to all those who have made contributions to the field of quick tests for available plant foods.

Even though the extracting solution used in the present work is very different from that used by Bray (9), it is the desire of the writer to acknowledge him as the one who initiated the work of using HClO_4 as an extracting solution of plant foods. It is further desired to acknowledge with appreciation the assistance of Mr. Marvin Geiger, Experiment Station Chemist, State College, Mississippi, for determining the exchangeable potassium of certain soils; to the recent Mr. C. T. Ames, Superintendent of Branch Experiment Station, Holly Springs, Mississippi, for furnishing certain soil samples; to Dr. Clarence Dorman, Assistant Director, Mississippi Experiment Station, State College, Mississippi, for furnishing yield data on fertilizer rates and analysis tests; to the officials of the Mississippi Experiment Station for making this study possible in granting a leave of absence to the writer; and especially to acknowledge with grateful appreciation Dr. R. P. Thomas, Soil Technologist of Maryland Experiment Station, College Park, Maryland, for supervising the work.

INTRODUCTION

In some parts of the country a great deal of time and effort has been devoted to rapid testing of soils for plant food deficiencies. These tests in the hands of experienced workers have made a very definite contribution to fertilizer practices in those areas.

Thomas' (74) survey showed, except tests for a few individual ions, that very little rapid testing had been done in the extreme South. There are several reasons for this. Owing to the mild climate, abundant rainfall, broken topography, and cropping practices the organic matter content is low, considerable erosion occurs, and as a result the general status of fertility of the soil is comparatively low. A satisfactory test must therefore be able to make minute differentiations. None of the methods which are most extensively used elsewhere have given the desired results. Because of this fact and because of the demand for such work, the present study was undertaken.

REVIEW OF LITERATURE

Quick tests as used today for determining plant food deficiencies in the soils are of comparatively recent development. There has been a great deal of work done in this field, however, during the last three-quarters of a century. Many schemes have been proposed and used for estimating these deficiencies. A brief review of these is given to lay the foundation for the present work.

The technique and reagents used in determining the individual ions have been greatly improved during the last few years. Since, however, the purpose of the whole effort is to determine the presence and abundance of the recognized essential ions that are available, the extracting solution seems to be the basic factor. If the work is approached from this angle, the previous work can be roughly divided into three periods, namely:

1. Early development to 1900 - Various weak acids were used.
2. From 1900 to 1920 - Water was used.
3. From 1920 to date - The trend has been back toward weak acids and to biological tests.

During the early development practically all of the work was done in Europe. Dilute solutions of hydrochloric acid, nitric acid, ammonium citrate, ammonium oxalate, citric acid, acetic acid, carbon dioxide saturated water, and some stronger solutions such as aqua regia were used as extracting solutions by such men as Liebig (43), Deherain (17), Vogel (84), Dugast (21), Lechartier (42), Stutzer (71), Eggertz and Nilson (23), and Dyer (22). Dyer's work perhaps exerted the greatest influence upon quick testing of all work done during this period. He did an extensive piece of work on the acidity of feeding roots of many different kinds of plants. The range in acidity, expressed as citric acid which he proposed to use, was from 0.34% to 3.4%. The

average of all plants was 0.93%. He thought that if an extracting solution comparable to the sap of feeding roots were used, comparable values of the essential ions could be had. Therefore, he made his extracting solution 1% citric acid. This method showed fair agreement with crop yields, and consequently has been used a great deal and is still used some in Europe. Most of the work was done on phosphorus.

During the period 1900 to 1920 most of the work was done in the United States. King (41) initiated the effort, using water as an extractant. About the same time Whitney and Cameron (86), and Snyder (68), and a little later Schreiner and Failyer (62) did considerable work on quick testing, all using water as an extractant. The progress of quick testing was perhaps arrested during this period on account of lack of agreement in interpreting the data secured. Whitney and Cameron's (86) work attracted a great deal of attention. Based on the results of this work, they concluded that practically all soils gave essentially identical solutions and that even where a small quantity of one constituent was present it was sufficient in quantity for a fair crop if the mechanical condition of the soil were good. Further deductions led them to suggest that the soil moisture was practically a saturated solution of mineral substances present in the soil. This led them to conclude that the controlling factors of fertility were moisture and physical condition of the soil, and not fertilizers and plant nutrients.

King (41) and Snyder (68) reached conclusions just opposite to those set forth by Whitney and Cameron. King found that the soil solution varied a great deal in concentration of soluble salts, and that it is higher on fertilized soils.

Since 1920 the trend has been back toward weak acids. Shedd (64) in 1920 reported the use of 0.2 N. nitric acid as an extracting solution. A little later it was brought out (2) (18) (53) (65) (82) and (88) that for the determination of certain ions, particularly phosphorus, the concentration

of the acid and the pH value of the extracting solution had to be accurately controlled. Otherwise the color developed was not necessarily a true picture of the phosphorus present. It was further revealed that there are certain ions, such as arsenic, ferric iron, and silica, which when present in large concentrations give similar colorations to that of phosphorus.

From 1925 to the present, an enormous amount of work has been done on testing soils for available plant foods. For the first few years phosphorus continued to be the center of interest, but gradually gave way, in part, to calcium or lime requirements, potassium deficiencies, and deleterious materials of the soil in general. Many different extracting solutions, methods of extraction, periods of time of contact between soil and solution, degrees of agitation, and dilution of soil extracting solution continued to be used.

According to a recent survey made by Thomas (74) most of the quick testing for available plant food nutrients is done in a few central, eastern, and northeastern states, with the exception of certain tests for individual ions. The extraction solutions most extensively used were Morgan's, Spurway's, Bray's, and Truog's, or a modification of these. Morgan's (50) solution is similar to the one used by Dahlberg and Brown (14), in that it is a solution of acetic acid buffered to a pH of 4.8, whereas Dahlberg and Brown buffered theirs to a pH 5. Spurway's (69) solution consists of one part of acetic acid to three parts of water. Bray's solution is made from hydrochloric acid and ammonium molybdate of approximately 0.7 N acid concentration. Truog's (81) solution is a 0.002 N solution of sulfuric acid buffered at a pH 3 with ammonium sulfate (His present solution is approximately .015 N HCl). This shows considerable variations in the concentration of acid in the various extracting solutions. These differences may be partially overcome, however, by varying the time of contact between the soil and the solution and by the degree of agitation.

Other methods have been used in making rapid tests for plant food deficiencies of the soil. Several biological tests, such as aspergillus niger by Dox (20), Azotobacter by Winogradsky, the Growth of Rye Seedlings by Neubauer, and Plant Tissue Tests by Hoffer (37), have been used. McGeorge (45) proposed and used electro dialysis as a means of measuring available phosphorus. Others (68) (46) (15) have used replaceable potassium to represent the amount of available potassium in the soil.

EXPERIMENTAL

An attempt is made to find an extracting solution which will extract plant foods available to plants under southern conditions. Since several of the above mentioned solutions serve a good purpose in other parts of the country, it seemed well to study those used most extensively under local conditions for a possible lead. The results of these solutions were therefore compared on a soil of known fertilizer treatment and yield history. Bray's (1) newly proposed perchloric acid solution was included in the comparison.

The perchloric acid solution promised to be the best possibility of the group. The soil extract was much clearer and considerably more phosphorus was extracted. All other extractants were discarded and a more detailed study was made of this solution. In this preliminary work, three rather serious handicaps were encountered in connection with this method, namely:

1. If the solution were made from the salt, it could not be used in testing for SO_4 and NO_3 because of their presence in the salt as impurities.
2. If the acid and Na_2CO_3 were used in making the solution, the test was long and tedious.
3. If the solution were made from either the salt or the acid, it was not buffered and therefore not satisfactory for soils of great variations in pH values, such as are encountered in the South.

The buffered perchloric acid solution is made by dissolving 40.75 grams of C.P. sodium hydroxide in distilled water, adding 150 ml of 71 per cent perchloric acid, 100 grams of sodium acetate and making the volume up to a liter. This results in an approximate .62 N solution in titratable acidity and a pH of 2. The use of this solution overcomes the above mentioned objections. Furthermore, an attempt is made to correlate the results from this method with the productivity of the soil. Samples of soil were collected from different levels of fertility of the same series, and from several different fertilizer rates and ratios tests, and were brought into the laboratory and studied. The study can be divided into three general divisions, namely:

1. A comparative study of soils from different levels of fertility on the same series.
2. A study of relative plant responses in the greenhouse, the amount of exchangeable potassium and rapid test values of soils from fertilizer rates and ratios tests.
3. A study of rapid test values, fertilizer treatments, forms of phosphorus and crop yields of soils taken from several fertilizer rates and ratios tests of several years standing under field conditions.

A brief outline of procedure used in each instance is given below.

A Comparative Study of Soils from the Same Series from Different Levels of Fertility.

A number of different important agricultural soils were included in this study. Two samples were taken from each soil series, one representing the higher status of fertility and the other the lower. Samples were taken from extremes in fertility in so far as was possible to be had in close proximity to each other. Pictures were made as to the status of vegetative growth at the place the samples were taken. In no instance were the samples taken more than fifty yards apart. The samples were brought into the laboratory, air-dried, put through a 20 mesh sieve and the rapid test values determined.

Tests for Individual Ions

Extraction was accomplished as Williams and Thomas (75) described by subjecting one teaspoonful (approximately 5 grams) of soil to the extraction solution for 20 minutes. This was done by placing a rubber policeman on the end of the funnel stem to retain the extracting solution. Ten ml. of the extracting solution were added to a 50 mm. funnel, which had as a filter a 20 mm. fritted glass disc. (porosity of 1). The soil was then added and allowed to stand undisturbed for 20 minutes. At the expiration of that time the policeman was removed, and the solution was allowed to drain thru the soil. The leachate was received in a 50 ml. Erlenmeyer flask. Aliquots of this solution were used for making the determinations of the several ions. A 0.5 ml. portion was used for each of the following tests; calcium, ferric iron, magnesium, manganese, phosphorus, potassium, and sulfate. The aluminum, nitrate nitrogen, and ammonia nitrogen were detected on one, one, and four drops respectively. Organic matter was determined according to Thomas and Williams' (75) modifications of Schollenberger's quick method (59). The pH values were determined with a Beckman glass electrode pH meter.

All tests except organic matter content and pH values were made on pyrex spot plates, No. 2001, under a day light lamp. Thomas* (73) found that accuracy of reading the amounts of the several materials present was facilitated by placing two intersecting ink lines of different widths immediately beneath the bottom of each spot indentation of the plate. One line should be drawn as fine as possible with an inking pen and the other from 0.5 to 0.75 mm. wide, so that each will be obscured at different intensities of colorations, turbidity, or precipitation as the case may be. The intersecting line chart can be held in place by putting a piece of plate glass over it.

In the determination of the quantity of the several compounds present no color charts were used, nor will any description of colors be given. It is

the opinion of the writer that it is a physical impossibility to give the accurate color picture through photography or in written description. In order to fix the color range firmly in the mind of the investigator, standard chemical solutions ranging in concentration from very high to no tests for the particular ion were used. Colors developed by this procedure are not always identical with those developed in soil extracts containing similar quantities of the element concerned, but are nearer the correct color than standard color charts.

Procedure for Determining the Several Elements

Aluminum

This element was determined by adding two drops of a saturated solution of haematin in 95% ethyl alcohol to one drop of soil extract.

Ammonia

Ammonia was determined by placing four drops of the extract in the spot and adding one drop of Nessler's solution.

Calcium

This element was determined by adding two drops of a saturated solution of sodium oxalate in 2% solution of sodium hydroxide to 0.5 ml. of soil extract in the spot plate. If the calcium content of the extract is excessively high, as indicated by a heavy instantaneous precipitation, three drops of sodium oxalate-hydroxide solution should be added.

Magnesium

Two tests were necessary for the determination of magnesium. One was designed for determining the higher range of magnesium. This test was made by

adding one drop of 0.01% solution of para-nitrobenzene-azoresorcenol in a 1% solution of sodium hydroxide to a 0.5 ml. of soil extract and then adding two drops of a 15% solution of sodium hydroxide as was used by Morgan (49). The other test is more sensitive than the first and is therefore designed to determine small quantities of magnesium. The test is made by adding one drop of Titan yellow solution (0.15% in 50 ml. of Methyl alcohol and 50 ml. of distilled water), to 0.5 ml. of soil extract and two drops of 15% solution of sodium hydroxide.

Manganese

To 0.5 ml. of soil extract was added one drop of 85% phosphoric acid and a few crystals of potassium periodate.

Ferric Iron

This element was determined by adding two drops of a saturated solution of sodium thiocyanate to 0.5 ml. of soil extract.

Nitrate Nitrogen

One drop of soil extract was placed in the spot plate and four drops of a solution of 0.2% diphenylamine in concentrated sulfuric acid were added.

Phosphorus

To a 0.5 ml. of soil extract was added one drop of 6% ammonium molybdate in 40% sulfuric acid solution. The two solutions were thoroughly mixed in the spot plate, and one drop of a saturated solution of stannous oxalate in perchloric acid extracting solution was added.

Potassium

One drop of a solution, saturated first with sodium cobalti-nitrite and then with sodium nitrate and filtered, was added to 0.5 ml. of soil extract. The reagent was thoroughly mixed with the extract and then four drops of absolute ethyl alcohol as used by Thomas (73) were added.

Sulfates

One drop of a 10% solution of barium chloride was added to 0.5 ml. of soil extract.

Organic Matter

One teaspoonful (approximately 5 grams) of soil was placed in a 200 ml. flask. To this were added 25 ml. of sodium dichromate solution (containing 200 grams of the salt per liter) and 25 ml. of concentrated sulfuric acid. After the mixture had cooled to approximately 40° C. it was diluted to 200 ml. with water, mixed, and 10 ml. aliquots were taken for titration with ferrous ammonium sulfate. The latter solution contained 100 grams of the salt and 25 ml. of sulfuric acid per liter. The samples for titration were diluted with from 10-20 ml. of water. Three ml. of concentrated sulfuric acid and two drops of orthophenanthroline, for indicator, were added to the samples before titration.

A blank solution of sodium dichromate was titrated first, and then the soil sample was titrated. The difference between the amount of ferrous ammonium sulfate used on the soil sample and on the blank is the amount of dichromate used in oxidizing the organic matter. Each ml. difference of ferrous ammonium sulfate used in the two titrations represents approximately 0.5% of organic matter.

The pH values were determined by placing a teaspoonful (approximately 5 grams) of (20 mesh sieve) soil in a 25 ml. capacity test tube and adding 10 ml. of distilled water. It was then allowed to come to an equilibrium, mixed, and the pH values were determined with the Beckman glass electrode pH meter.

With the exception of organic matter content which was reported in percentage and the pH values which were reported as such, the quantities of the several elements present in the soil were indicated by letters. The letters used were as follows: None (O), trace (T), low (L), medium (M), high (H), and very high (X). The tests for the individual ions in the buffered perchloric acid solution were calibrated according to the range in pounds per acre and milligrams per aliquot of element concerned, according to Thomas and Williams (75), with the exception of sulfates. Sulfates are usually found in the soil only in small quantities.

With the buffered perchloric acid extractant the differences in the time required for the test reagents to react with the aliquots of soil extract can be conveniently handled by the sequence of adding the reagents and subsequent reading of them. The reagents were added in the following sequence: manganese, potassium, magnesium, sulfates, calcium, phosphorus, nitrate, ammonia, aluminum, and iron. Subsequently the readings were made in the following order: iron, aluminum, ammonia, nitrates, phosphorus, calcium, sulfates, magnesium, potassium, and manganese.

A Study of the Relative Plant Responses in the Greenhouse, The
Amount of Exchangeable Potassium, and Rapid Test Values
of Soils from Fertilizer Rates and Ratios Tests

For this portion of the study samples were taken from fertilizer rates and ratios tests on Ocklocknee fine sandy loam. Four kilograms of soil were

placed in one gallon capacity glazed pots and planted to rye. When the plants had germinated, they were thinned to eight plants per pot. Two hundred grams of soil were taken from each pot and the exchangeable potassium determined, after the method of Schollenberger and Dreibelbis (61). When the plants were about eight inches high, a picture was made of them. At maturity the rye was harvested and the yields secured.

A Study of Rapid Test Values, Fertilizer Treatment, Forms
of Phosphorus, and Crop Yields of Soils Taken from
Several Fertilizer Rates and Ratios Tests of
Several Years Standing Under Field
Conditions

Three important soil types were included in this part of the study. Samples were taken from fertilizer rates and ratios tests of ten or more years standing on each soil, brought into the laboratory, and rapid test values were determined. The fertilizer treatments, crop yields and rapid test values are brought together and their relationship studied.

As a check upon the phosphorus results obtained by the buffered perchloric acid solution, some of the soils were analyzed for different forms of phosphorus by Fisher and Thomas' (24) method.

RESULTS AND DISCUSSION

Perchloric acid was compared with several of the most extensively used extracting solutions employed in determining soil deficiencies by rapid tests. The perchloric acid is a mineral acid and therefore gives a clearer soil extract than organic acid extractants. This was very helpful in reading all turbidity tests, particularly that of potassium. This acid has a higher ionization constant and is used in a more concentrated form (.62N in titratable acidity

with a pH of 2) and is therefore able to extract more phosphorus than other extractants. The study revealed that it was necessary to buffer the solution in order for it to have equal extracting power in soils with great variations in pH values. Making the extracting solution from perchloric acid, sodium hydroxide, and sodium acetate is a simple task and resulted in a well buffered solution that would permit testing for sulfates, nitrates, and chlorides. This would not be true of most other strong mineral acids.

The object in testing the soils for plant food deficiencies from different levels of fertility on the same series were, first, to ascertain if the method would make minute differentiations and, secondly, to reveal the deficiency or disturbing factors of the soil so that the evil might be corrected. This whole group of soils ranged in productivity from medium to very low. The results are reported in Table 1. A critical study of the Table reveals that there are some textural differences in certain of the soils that are being compared. These differences, however, are very small and probably do not exert a significant influence upon the amount of available plant food present.

The principal differences in the soils were that the more productive soils were, in general, higher in organic matter, calcium, magnesium, and pH values, whereas iron and aluminum were higher in the less productive soils.

Burgess and Pember (12) found that active aluminum exercised very definite inhibitory forces upon plant growth. The solubility of aluminum is directly correlated with the acidity of the soil, increasing rapidly below a pH of 5.4.

With three exceptions the less productive soils had a pH too low for optimum plant growth, which is no doubt either directly or indirectly responsible for their low productivity. The exceptions were Myatt (number 5), Ruston (number 9), and Houston (number 11). The Myatt is a bottom soil,

and in this case is covered with material from the surrounding limestone hillsides. There appeared to be no significant differences between the two samples of Ruston. The explanation of the Houston soils, being an exception, lies in its parent material. It is derived from Selma chalk; and owing to erosion has limestone material cropping out where this sample was taken. The difference in productiveness in samples number 11 and 12 is perhaps due to a physical relationship rather than a chemical one. Sample number 12 comes from an area that has several inches of top soil to retain the moisture, whereas sample number 11 has very little soil material. These data indicate that the buffered extracting solution removed the plant food in about the same order as it is removed by the growing plant, and revealed the presence and approximate quantities of disturbing substances.

The differences in growth of rye in the greenhouse on the Ocklocknee soil taken from rates and ratios tests were very pronounced at first. When the plants were a month old, there was a regular increase in growth for each additional increment of potassium that had been applied. This is shown in plate No. 20. At maturity no consistent differences were found, in total growth, size of head, or total grain due to potassium treatments. The results are reported in Table 2. This soil responded quite well to potassium treatments under field conditions, which would tend to indicate that the soil was low in soluble potassium. There was, however, enough residual potassium in the soils receiving high applications to give the plants a very good start. The initial supply was exhausted long before the plant reached maturity, and thus exerted no influence upon the ultimate growth or yield.

Table 2 also shows the exchangeable potassium found in the Ocklocknee soil following various treatments. The plot receiving 72 pounds of K_2O (or the 600 lbs. of 4-8-12) was an untreated plot until five years ago. During the last five years this plot has received 72 pounds of K_2O annually. All

plots receiving more than 72 pounds of K_2O per acre annually have been receiving it only for the last five years. The relatively small quantities of potassium found following the higher applications of complete fertilizer are perhaps due to potassium fixations by phosphorus. Joffe and Kolodny (40) found that potassium was fixed by soluble phosphorus. This fact seems to be borne out in these data since untreated soil had more replaceable K than the soil receiving 600 pounds of 4-8-4. The greatest increase in exchangeable potassium occurred where the phosphorus was held constant and the potassium increased to 48 pounds of K_2O per acre. Above that point the phosphorus application was likewise increased; therefore, more potassium was probably fixed. It seems to be generally accepted that only exchangeable cations are available to plants. In Table No. 2 the results of the rapid test are also shown. They are not in perfect agreement with the exchangeable potassium found. The rapid test showed more potassium under the higher applications, and these results are in agreement with yields on these plots. This seems to indicate that more potassium might be available than is found in an exchangeable form, which is in agreement with the results of Gedroiz (28) and Proebsting (57). Gedroiz investigated calcium and magnesium and found almost normal yields after practically complete displacement of both cations. Proebsting concluded that neither water soluble nor exchangeable potassium was an accurate index of the soil's ability to supply potassium and that the non-exchangeable potassium may constitute a very important source of supply to certain plants.

The average yields of seed cotton on several different soils variously treated under field conditions and the results obtained from the buffered perchloric acid method are recorded in Tables 3 to 5 inclusive. Table No. 3 gives the results of Ocklocknee fine sandy loam. It is a valley soil of the coastal plain area, and is above the average in productivity.

Since nitrogen, phosphorus, and potassium are the only variations in treatment and since nitrogen is very unstable in the soil, major emphasis is placed upon phosphorus and potassium and their relationship to yields and rapid test values.

The yield data from the Lufkin and Ocklocknee soils were analyzed by statistical methods for differences due to treatments. In the case of the Ocklocknee, it was found that the first increase in phosphorus over the minimum application did not give significant increases in yield, but that the second increase in the phosphorus application was significant. This was not in agreement with the rapid test. The minimum application of potassium gave a significant increase over no potassium, but further increases in applications were not significant. This is in perfect agreement with the results of the rapid test, as a L amount of potassium seemed to supply sufficient potash for growth. The plots receiving the 1200, 1800, and 2400 pound applications of complete fertilizer gave considerable increases in the amount of soluble materials of all elements applied.

The results on Lufkin clay are reported in Table 4. This is an upland, level to undulating soil, is very high in colloidal material, and has a very stiff, sticky subsoil which restricts internal drainage. It is considered a submarginal soil for general agricultural purposes, but is farmed considerably in certain areas. The results are not very consistent, either in yields or quick test data. Phosphorus variations failed to give any significant differences, and potassium was inconsistent. The rapid tests agreed with the yield data in that the fertilizer treatments did not give consistent increase in yields. This study reveals that the limiting factor in this soil is a physical phenomenon rather than a nutrient deficiency.

Table 5 gives the results from Lintonia silt loam, which is a valley soil derived from Loessal material and is above the average in productivity.

There is an almost perfect relationship between the amounts of potassium applied, increases in yields, and amounts of potassium found by the rapid test. Small increases in yields and available phosphorus were secured from increases in phosphorus application. There was, however, a definite relationship between the amounts of phosphorus applied and the amount found by the rapid test.

Tables Nos. 3 and 4, reporting the yields of seed cotton as affected by fertilizer treatments on Ocklocknee and Lufkin soils respectively, showed very small increases due to phosphorus treatments. Since there were some inconsistencies between phosphorus applications, yields, and quick test results, it seemed well to ascertain what forms of phosphorus were present. This was done according to Fisher and Thomas' method (24). This method divides the phosphorus into three parts, namely: A, which is primarily calcium and magnesium phosphates; B, which is easily soluble iron and aluminum phosphates; and C, which is relatively insoluble iron and aluminum phosphates. These results are reported along with the yields of seed cotton and rapid test values and Ocklocknee and Lufkin soils in Tables No. 6 and 7 respectively.

It is believed that calcium and magnesium phosphates are soon converted to iron and aluminum phosphates when applied to the soil under Southern conditions. A part of these newly formed phosphates may be available to plants; Truog (81) suggests that they are available. This seems to be borne out in these data, since very little calcium and magnesium phosphates (from 14 to 46 pounds per acre) were found in the Ocklocknee soil and yet very poor responses to additional application of phosphorus were secured. If the relatively large amounts of easily soluble iron and aluminum phosphates (from 88 to 308 pounds per acre) found are also available to plants, then obviously the plants would not respond to additional applications of phosphorus. The total amounts of phosphorus found in the three different forms correlated with the amounts applied up to and including 1200 pounds of 4-8-8 per acre. The sample from

the plot receiving 600 pounds of 6-8-8 per acre was relatively low (88 pounds per acre) in ~~in~~ easily soluble iron and aluminum phosphates but was high (112 pounds per acre) in the relatively insoluble iron and aluminum phosphates. Even in this instance, however, the combined calcium and magnesium and relatively soluble iron and aluminum phosphates give a total of 134 pounds which is sufficient to produce a medium crop. Furthermore, Truog (83) thinks that some of the most "difficultly soluble" forms of phosphorus found in soils may be available to plants.

A critical examination of Table 6 reveals that the combined calcium and magnesium and relatively soluble iron and aluminum phosphate content is quite high (172 pounds per acre) even where no fertilizers had been applied. The yield of seed cotton was 608 pounds per acre. This is almost equal to the state average in production prior to the 1937 crop, which indicates that it is a fertile soil. The amounts of phosphorus found by the quick test are in general agreement with the combined calcium and magnesium, and iron and aluminum phosphates found.

It is usually conceded that organic extractants such as sodium acetate, remove only the calcium and magnesium phosphates from the soil. The sodium acetate extracting solution was compared to the buffered perchloric acid solution on other soils than those included in this study, and found to be consistently lower in its extracted phosphorus content. These actual yield data indicate that at least a good portion of the iron and aluminum phosphates are utilized by the plants. It logically follows that extracting solutions which extract only the calcium and magnesium phosphates would not give a true picture of the phosphorus deficiencies in these soils. This, no doubt, is one reason why the sodium acetate or "universal" extracting solution, has failed to give satisfactory results under Southern conditions.

In addition to the phosphorus inconsistencies as secured by the methods ordinarily used, Bray (9) states that sodium perchlorate in fairly concentrated solutions has the ability to remove 100 per cent of the replaceable potassium from soils with low exchange capacities and almost 100 per cent from soils with high base exchange capacities. He further states that the only other feasible extracting solution known to replace practically all of the replaceable potassium is a solution of 30 per cent sodium acetate plus 15 per cent nitric acid. The concentration of the sodium acetate in the latter solution is much greater than is used in the orthodox methods. What is a great deal more important from the standpoint of extracting potassium, however, is the fact that 15 per cent nitric acid gives a strong solution of a mineral acid. This solution, even though it is well buffered and capable of removing all exchangeable potassium, would not permit testing for nitrates because of the nitric acid present.

A satisfactory extracting solution for quick testing of soils should not only reveal an accurate picture of the presence and abundance of phosphorus and potassium in the soils, but also the nitrogen, calcium, magnesium, iron, aluminum and manganese content. The tests should also include the easily activated organic matter and the pH value of the soils. All of this information assists in presenting the picture as it exists in nature and is therefore essential in making an intelligent recommendation for the soil. Recommendations are based upon a very minute portion of soil and it is therefore of utmost importance that the samples be taken correctly. Even with the greatest of care it is easy to conceive of a composite sample being contaminated to the extent that the results on one or two of the tests, such as phosphorus or pH, could be misleading unless all tests were made and the interrelationship between all of the compounds properly considered. Nitrogen content might be quite high just prior to the planting of a long growing summer crop but would no doubt need

an application of nitrogen before it reached maturity. Another soil may be high in colloidal material and have sufficient quantity of all of the compounds needed for good plant growth and yet have toxic quantities of aluminum and manganese. A soil may have a low pH indicating that such crops as asparagus and red clover would not grow, but the calcium and magnesium content may be relatively high. Since these plants are calcium loving plants rather than high pH loving plants, they may grow well on this soil.

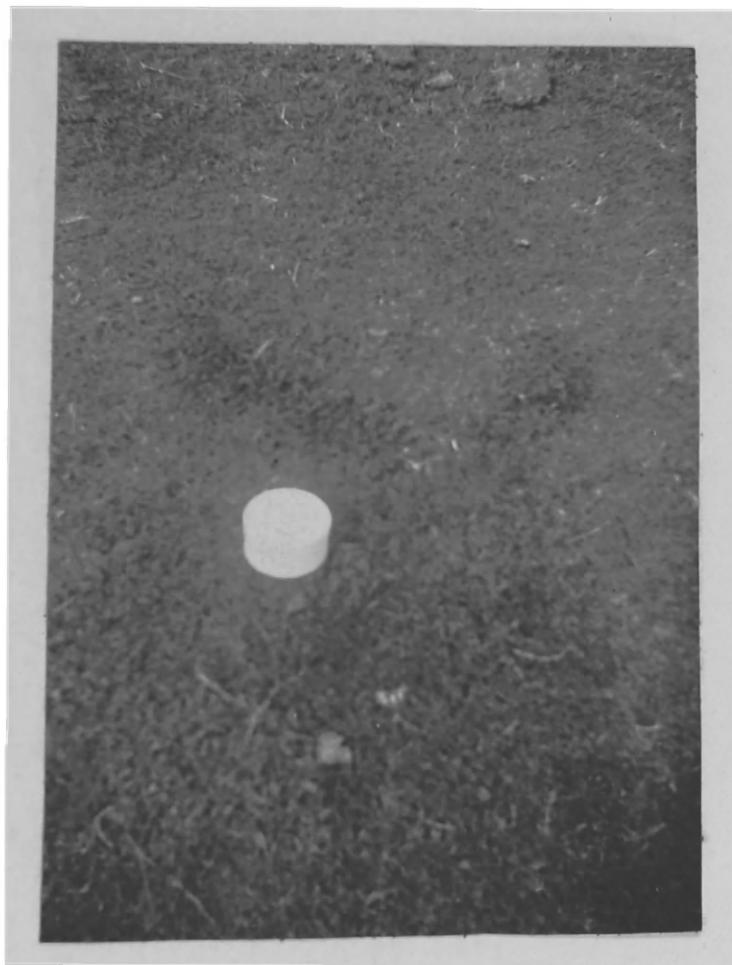
The buffered perchloric acid extracting solution permits the testing for all of the important elements of plant foods and disturbing substances of the soil.

PLATE I.



ОУТІБЕРА FINE SANDY LOAM COVERED WITH A VERY POOR SOD

PLATE 2.



OKTIBBEHA SANDY LOAM COVERED WITH A GOOD SOD

PLATE 3.



. OYTIBBEHA FINE SANDY LOAM COVERED WITH HENBIT

PLATE 4.



OKTIBBEHA FINE SANDY LOAM COVERED WITH BUR CLOVER AND HAIRY VETCH

PLATE 5.



MYATT SANDY LOAM SHOWING A VERY POOR GROWTH OF COTTON

PLATE 6



LYATT FINE SANDY LOAM SHOWING A MEDIUM GROWTH OF COTTON

PLATE 7.



. OKTIBBEHA FINE SANDY LOAM SHOWING A POOR GROWTH OF COTTON

PLATE 8.



.OKTIBBEHA FINE SANDY LOAM SHOWING A MEDIUM GROWTH OF COTTON

PLATE 9.



RUSTON VERY FINE SANDY LOAM COVERED WITH A POOR GROWTH OF VETCH

PLATE 10.



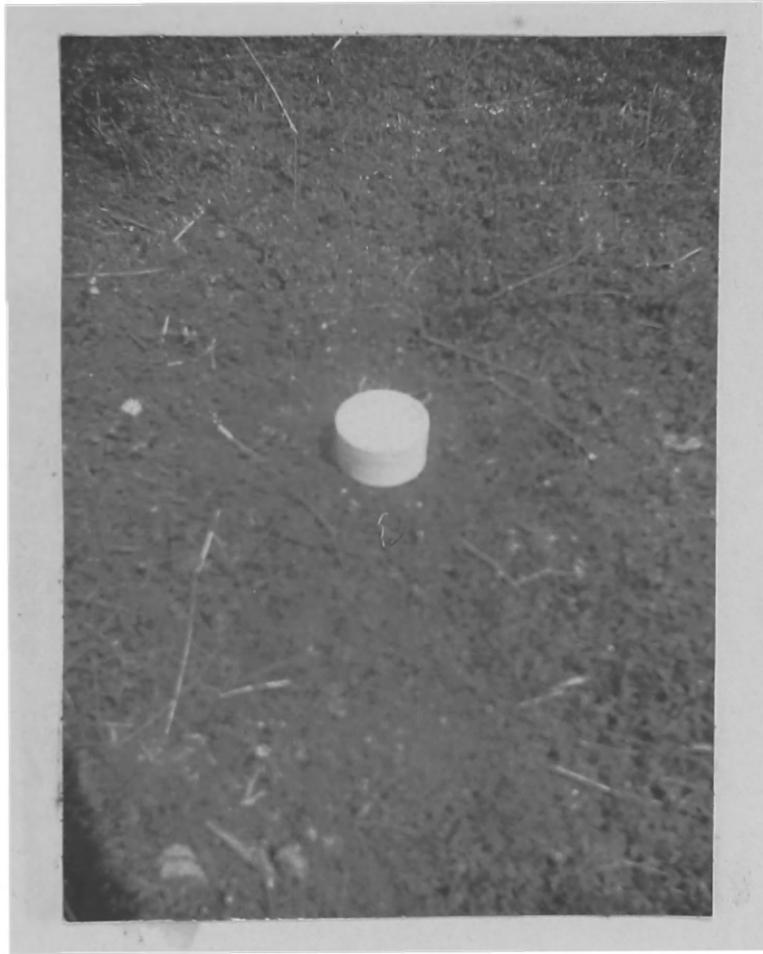
RUSTON VERY FINE SANDY LOAM COVERED WITH A MEDIUM GROWTH OF VETCH

PLATE 11.



HOUSTON FINE SANDY LOAM COVERED WITH A POOR SOD

PLATE 12.



HOUSTON FINE SANDY LOAM COVERED WITH A GOOD SOD

PLATE 13.



HOUSTON FINE SANDY LOAM SHOWING A POOR GROWTH OF CORN

PLATE 14.



HOUSTON SANDY LOAM SHOWING A GOOD GROWTH OF CORN

PLATE 15.



KIRVIN VERY FINE SANDY LOAM SHOWING A VERY POOR GROWTH OF COTTON

PLATE 16.



KIRVIN VERY FINE SANDY LOAM COVERED WITH A MEDIUM GROWTH OF COTTON

PLATE 17.



LUFKIN SANDY LOAM SHOWING MEDIUM GROWTH OF COTTON

PLATE 18.



LUFKIN SANDY LOAM, 1st TWO INCHES UNDER FOREST COVER

PLATE 19



RELATIVE GROWTH OF RYE PLANTS AS AFFECTED BY VARIATIONS OF
POTASSIUM TREATMENT ON OCKLOCKNEE FINE SANDY LOAM

TABLE I.--A Comparison of Vegetative Growth and the Amounts of Ions Extracted by the Buffered Perchloric Acid Solution on Several Important Southern Soils

Soil Type	Vegetation	pH value	Amounts of ions extracted by buffered perchloric acid solution											Per cent organic matter
			Ca	Mg	Al	Fe	NO ₃	NH ₄	P	K	Mn	SO ₄		
1. Oktibbeha fine sandy loam	Very poor sod	4.98	M	T	X	-H	T	-L	-	-H	-	-	.4	
2. Oktibbeha sandy loam	Good sod	5.51	M	LM	L	M	T	M	T	HL	-	-	4.5	
3. Oktibbeha fine sandy loam	Weeds	4.94	-L	-L	M	-L	T	L	L	T	-	-	.3	
4. Oktibbeha fine sandy loam	Legumes	5.40	L	HL	M	L	T	HL	-L	-	-	-	1.0	
5. Myatt sandy loam	Very poor cotton	6.08	-H	-M	L	-	T	-L	T	T	-	-	.4	
6. Myatt fine sandy loam	Medium cotton	6.94	H	H	T	-	T	L	T	L	T	-	1.4	
7. Oktibbeha fine sandy loam	Poor cotton	5.36	M	T	X	-H	T	L	T	L	-	-	0.0	
8. Oktibbeha fine sandy loam	Medium cotton	5.88	H	M	L	T	T	-M	T	L	-	-	.7	
9. Ruston very fine sandy loam	Poor vetch	6.17	L	L	L	T	T	-L	T	L	L	-	.4	
10. Ruston very fine sandy loam	Medium vetch	6.08	HT	HT	L	T	T	-L	-L	-	HT	-	.3	
11. Houston clay loam	Poor sod	7.51	X	-M	-	-	T	LM	M	T	T	-	2.1	
12. Houston clay loam	Good sod	6.54	H	M	-	T	T	LM	T	M	-	-	3.3	
13. Houston clay loam	Poor corn	5.54	H	HT	M	T	M	HL	-	T	M	-	1.4	
14. Houston clay loam	Good corn	6.37	H	-M	T	-	T	HL	T	HT	T	-	1.6	
15. Kirvin very fine sandy loam	Poor cotton	5.46	HL	HL	M	T	-	-L	T	L	T	-	.0	
16. Kirvin very fine sandy loam	Medium cotton	5.70	-L	M	M	-	-	-L	T	T	T	-	1.1	
17. Lufkin sandy loam	Medium cotton	4.94	M	-M	H	-M	-L	LM	T	-M	X	-	1.1	
18. Lufkin sandy loam	1st. two inches forest cover	5.58	-H	-M	T	-L	T	M	T	HM	L	L	5.1	
19. Lufkin sandy loam	First foot forest cover	5.27	T	L	H	H	-	L	T	H	L	-	1.5	

TABLE II.--The Residual Effect of Fertilizer Treatment upon Ocklocknee Fine Sandy Loam from Fertilizer Rates and Ratios Tests upon Yields of Rye, Exchangeable Potassium and Rapid Test Values under Greenhouse Conditions

Treatment	12 yr. avr. yield of seed cotton in the field	Mille-equiv. of K. found	Yields of Rye		Rapid test values of K.
			Grain	Stalks and leaves	
No treatment	608#	.182	0.32 grms.	4.70 grms.	T
4-8-4 600#	1026	.168	0.10 "	3.65 "	L
4-8-6 600#	1071	.259	0.12 "	3.28 "	L
4-8-8 600#	1096	.309	0.38 "	4.90 "	L
4-8-12 600#	985	.279	0.27 "	4.47 "	L
4-8-8 1200#	1149	.235	0.36 "	5.36 "	M
4-8-8 1800#	1118	.313	0.03 "	5.12 "	H
4-8-8 2400#	1075	.303	0.31 "	4.60 "	X

TABLE III.--The Influence of Fertilizer Treatments on the Yields of Seed Cotton and the Ions Removed by the Buffered Perchloric Acid Solution on a Ocklocknee Fine Sandy Loam Soil

Treatment	12 yr. avr. yield of seed cotton in lbs. per acre	pH value	Amounts of ions extracted by the buffered perchloric acid solution										Per cent organic matter
			Ca	Mg	Al	Fe	NO ₃	NH ₄	P	K	Mn	SO ₄	
No treatment	608	6.51	H	M	T	-	L	M	T	T	T	-	0.5
4-8-0 600#	682	6.37	H	M	T	-	L	L	L	T	T	-	0.4
4-8-4 600#	1026	6.32	H	M	T	-	M	L	M	L	T	-	0.4
4-8-6 600#	1071	6.30	H	M	T	-	M	L	M	L	T	-	0.4
4-8-8 600#	1096	6.35	H	M	T	-	M	L	M	L	T	-	0.3
4-8-12 600#	985	6.35	H	H	T	-	M	L	L	L	T	-	0.8
4-6-8 600#	1030	6.39	H	M	T	-	M	L	M	L	T	-	0.8
4-4-8 600#	1005	6.42	H	M	T	-	M	L	L	L	T	-	0.5
4-8-8 1200#	1149	6.15	H	M	T	-	H	M	H	M	T	T	0.8
4-8-8 1800#	1118	5.99	H	M	T	-	H	H	H	H	T	L	1.2
4-8-8 2400#	1075	6.09	H	M	T	-	H	H	H	X	T	L	0.6

TABLE IV.--The Influence of Fertilizer Treatment on the Yields of Seed Cotton and the Ions Removed by the Buffered Perchloric Acid Solution on a Lufkin Clay Soil

Treatment	11 yr. avr. yield of seed cotton in lbs. per acre.	pH value	Amounts of ions extracted by the buffered perchloric acid solution										Per cent organic matter
			Ca	Mg	Al	Fe	NO ₃	NH ₄	P	K	Mn	SO ₄	
No treatment	299	4.8	M	M	L	L	T	M	-	T	T	-	.5
4-8-0 600#	570	4.9	M	M	H	T	L	L	L	T	T	-	.5
4-8-2 600#	582	4.3	H	M	H	L	L	L	L	T	L	-	.7
4-8-4 600#	629	5.3	M	M	M	M	L	L	T	T	L	-	.5
4-8-6 600#	622	5.8	H	M	M	H	L	M	L	M	T	-	.9
4-4-4 600#	569	6.1	H	M	L	L	L	H	T	L	T	-	.3
4-6-4 600#	623	5.6	H	M	L	H	T	M	L	M	T	-	.7
4-8-4 1200#	789	5.4	H	M	L	M	M	L	M	L	T	L	.9
4-8-4 1800#	892	5.4	H	M	L	T	M	M	M	H	T	M	1.2
4-8-4 2400#	981	5.6	H	M	L	L	X	H	H	X	T	H	.9

TABLE V.--The Influence of Fertilizer Treatments on the Yields of Seed Cotton and the Ions Removed by the Buffered Perchloric Acid Solution on Lintonia Silt Loam

Treatment	12 yr. avr. yield of seed cotton in lbs. per acre.	pH value	Amounts of ions extracted by the buffered perchloric acid solution										Per cent organic matter
			Ca	Mg	Al	Fe	NO ₃	NH ₄	P	K	Mn	SO ₄	
No treatment	889	6.62	H	M	T	-	T	M	HT	T	T	-	1.2
4-8-0 600#	1025	7.28	-H	M	-	-	T	-H	HL	L	L	-	1.6
4-8-2 600#	1257	6.81	-H	M	-	-	T	HM	L	L	L	-	1.3
4-8-4 600#	1433	6.85	-H	M	-	-	T	HL	L	HL	-L	-	1.6
4-8-6 600#	1532	6.98	-H	M	-	-	T	M	L	M	L	-	1.2
4-8-8 600#	1599	6.94	H	M	-	-	T	M	HL	M	L	-	1.3
4-4-4 600#	1396	7.32	-H	M	-	-	T	-H	T	HL	HL	-	1.5
4-6-4 600#	1393	7.16	H	-M	-	-	T	M	HL	-M	HL	-	1.6
4-8-4 1000#	1528	6.85	-H	M	T	-	T	-L	M	HL	T	-	1.5
4-8-4 1200#	1526	7.09	H	M	-	-	T	HM	-H	X	HT	-	1.3

TABLE VI.--The Effect of Fertilizer Treatments Upon the Forms of Phosphorus in Ocklocknee Fine Sandy Loam

Treatment	Yield	Solution A	Solution B	Solution C.	Rapid Test Value of P
No treatment	608	18	154	0	HT
4-4-8 600#	1005	28	132	52	L
4-6-8 600#	1030	35	110	98	M
6-8-8 600#	1029	46	88	112	M
4-8-8 1200#	1149	22	308	0	H
4-8-8 1800#	1118	24	286	0	H
4-8-8 2400#	1075	14	297	0	H

TABLE VII.--The Effect of Fertilizer Treatments Upon the Forms of Phosphorus in Lufkin Clay

Treatment	Yield	Solution A	Solution B	Solution C.	Rapid Test Value of P
No treatment	299	0	154	0	-
4-4-4 600#	569	20	77	0	T
4-6-4 600#	623	28	132	0	L
4-8-4 600#	629	26	44	100	
4-8-4 1200#	789	0	506	0	M
4-8-4 1800#	892	12	363	80	M
4-8-4 2400#	981	38	528	0	H

SUMMARY

Soils from different states of fertility of the same series and soils from fertilizer rates and ratio tests of ten or more years standing on several soil types were brought into the laboratory and studied. The study included comparisons of rapid test values, yields, relative growth, forms of phosphorus, and amounts of exchangeable potassium on certain of the soils. Supporting evidence was secured from each of these approaches indicating that the essential ions were extracted from the soil in about the same proportion to that extracted by plants.

From the results of this study it is concluded that the buffered perchloric acid extracting solution is:

1. A well buffered extracting solution.
2. Easily made.
3. Permits testing for all ions essential for plant growth.
4. Secures the calcium and magnesium phosphates and a good portion of the easy soluble iron and aluminum phosphates, thus correlating with plant growth responses to phosphorus applications.
5. Secures practically all of the exchangeable potassium.
6. Gives a clearer soil extract than organic acid extractants.

It is further concluded that if all other factors are properly considered, the use of the buffered perchloric acid extracting solution in the rapid soil test gives a good picture of the fertilizer needs of the Southern soils such as are in Mississippi.

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